ADDRESSING AFFORDABILITY IN DEFENSE SCIENCE AND TECHNOLOGY

A HANDBOOK FOR S&T MANAGERS

October 1999

Prepared by
Manufacturing Technology
Information Analysis Center,
Production Technology Incorporated,
&
RFP Associates

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Affordability is receiving special attention within both the public and the private sectors. Within the public sector, particularly the DoD, diminished resources require greater emphasis to be given to affordability. The DoD affordability goal is to provide effective weapon and support systems - in the quantity and quality needed by the warfighter to carry out assigned missions - at a reduced cost. Affordability in the "cradle to grave" defense acquisition system needs to begin at the early stages of science and technology development and extend into acquisition and transition of the technology in order to obtain reduced acquisition and life cycle costs.

Dr. Paul G. Kaminski, former Undersecretary of Defense for Acquisition and Technology, defined affordability concisely in his remarks to the Acquisition and Technology Subcommittee of the Senate Armed Services Committee, as, "reducing development, production and ownership cost." He also stated that "Each technology effort must buy its way into our programs in terms of reducing life-cycle cost and program risk." The Honorable Jaques S. Gansler continued the affordability challenge in January, 1999, with publication of "Into the 21st Century: A Strategy for Affordability". He stated, "For this next phase of acquisition reform, we must further adapt the best world class business and technical practices to our needs, rationalize our infrastructure, restructure our support systems, and reduce cycle time and ownership costs while simultaneously improving readiness."

The requirement that each technology effort 'buy its way' into programs with 'reduced cycle time and ownership costs' has motivated the Science & Technology (S&T) community to attack the issue of affordability. As indicated in the Defense Science and Technology Strategy, the first of the four Strategic Investment Priorities is affordability. "Diminished resources require greater emphasis to be given to affordability throughout the S&T program. DoD acquisitions will not meet the warfighters' needs within current budgets unless we consider reduced costs of development, procurement and life-cycle operation in the S&T program." It is also recognized that technological innovations can result in reduced system costs but only if they can be affordably incorporated into systems. Hence, the S&T community has recognized the need to more closely align its activities to the needs of the system acquisition and logistics communities.

The S&T community must not forgo the legacy of providing the 'seed-corn' for future systems, but it must also incorporate the lessons of commercial industry. In every technological endeavor, the researcher makes 'choices' that eventually affect the utility and supportability of the final product. Commercial success has focused on developing an understanding of the effect of such choices. Stifling creativity is not the goal; providing an understanding of the long-range impact of 'choices' is.

The Manufacturing Technology Information Analysis Center (MTIAC) has worked with the DoD S&T Affordability Task Force (ATF), Production Technology Incorporated, and RFP Associates to develop a handbook for S&T program managers that captures the ideas, concepts, and best practices in implementing affordability practices in S&T. This handbook provides guidelines on how to address affordability in an S&T program. The earlier we consider affordability, the more effectively we influence the life cycle costs and the affordability of products for insertion into military systems.

Affordability best practices are outlined in examples of S&T program case studies that focus on customer involvement in the development and transition of technology. The customer – that is the DoD program office or systems integrator – should be involved early on in planning the transition of technology across one or more military systems. The technology transition process is reviewed – program office needs should be identified, program office management support should be formalized, affordability metrics established against which to measure progress, and producibility and manufacturing issues addressed throughout the program. Education and training modules are detailed to promote application of integrated process and product development principles in S&T development. Also selected affordability management tools are discussed – for example, integrated product and process development (IPPD), quality function deployment, design of experiments, and six sigma manufacturing.

ADDRESSING AFFORDABILITY IN DEFENSE SCIENCE AND TECHNOLOGY (S&T)

1.0 INTRODUCTION

Affordability is receiving special attention within both the public and the private sectors. Within the public sector - particularly the DoD - diminished resources require a greater affordability emphasis. The DoD affordability goal is to provide effective weapon and support systems, in the quantity and quality needed by the warfighter to carry out assigned missions, at a reduced cost. As shown in Figure 1-1, affordability not only addresses the issue of being able to afford to purchase the necessary quantity of weapons, but also being able to afford the support of these systems over very long periods of time. Affordability in the "cradle to grave" defense acquisition system needs to begin at the early stages of science and technology development and extend into acquisition and transition of the technology in order to obtain reduced acquisition and life cycle costs.

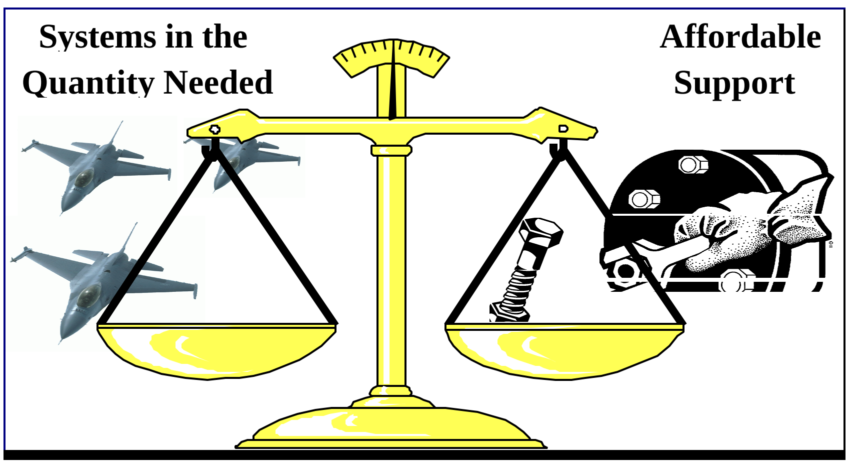

Figure 1-1. DoD Affordability Goal.

1.1 Definition of Affordability in Defense S&T. With respect to this handbook, "affordability" in S&T has dual definitions. On the one hand, affordability concerns the DoD's ability to acquire and maintain sufficient quantities of military equipment to achieve the department's strategy and objectives. Affordability addresses the notion of *best value* in terms of performance, producibility, life-cycle cost and risk. Hence, affordability efforts are directed at the cost-effective acquisition of high-performance systems and equipment and the cost-effective sustainment of those systems to accomplish the mission. Affordability may be achieved by reducing the life cycle cost of a given system and purchasing and maintaining the same number of systems. But it can also be achieved by devising new ways to achieve the mission that require fewer systems. While individual units or systems might be more costly to acquire and maintain, the net life cycle to achieve the mission may be reduced through significant improvements in performance and effectiveness. Affordability can also be achieved by developing new manufacturing processes that enable the low cost production and/or repairs of new weapons systems. Advances in manufacturing may significantly reduce non-recurring costs, such as hard tooling for composites, thus reducing the acquisition cost for items produced in volumes insufficient to amortize the high up-front costs typical of defense products.

Dr. Paul G. Kaminski, former Undersecretary of Defense for Acquisition and Technology, defined affordability concisely in his remarks to the Acquisition and Technology Subcommittee of the Senate Armed Services Committee, as, "reducing development, production and ownership cost." He also stated that "Each technology effort must buy its way into our programs in terms of reducing life-cycle cost and program risk." The Honorable Jaques S. Gansler enforced this in January, 1999, with publication of "Into the 21st Century: A Strategy for Affordability". He stated, "For this next phase of acquisition reform, we must further adapt the best world class business and technical practices to our needs, rationalize our infrastructure, restructure our support systems, and reduce cycle time and ownership costs while simultaneously improving readiness." The concern for life cycle cost is obvious. However, the bulk of life cycle cost is fixed long before it is spent. An example of how life cycle cost is fixed early in the life cycle is given by Boeing data on ballistic missile systems as summarized in Table 1-1.

TABLE 1-1: When Costs Become Fixed (Unchangeable).

By the end of:	% of LCC spent is:	% of LCC rendered unchangeable is:
Concept development	1.0	70
Advanced development	7.0	85
Full scale development	18	95
Production	50	97
Operations and support	100	100

As indicated, seventy percent of the total life cycle costs of the system are rendered unchangeable after only about one percent of the total costs are expended; eighty-five percent are unchangeable after only about seven percent are expended. Accordingly, affordability is largely determined during early development in the S&T stage.

That then brings us to our second definition of "affordability", which is as a code word or shorthand for a philosophy of program management and set of program management objectives and tools. In our view, a necessary but not sufficient condition of an affordability program is that it be concerned with cost, as elaborated above. But, it must also adopt an appropriate management philosophy, as described below.

1.2. Affordability Considerations in Science and Technology. Affordability is one of the strategic investment priorities of the Defense Science and Technology Strategy, which states "The S&T program provides options to enable modernization of our forces with smaller budgets." These options are provided in two ways:

First, technological innovations are produced that reduce system cost. An example is the development of embedded sensors that will alert maintenance personnel to the need for maintenance of structures such as airplane wings. This technology will eliminate unnecessary preventive maintenance inspections and more effectively prevent costly (and perhaps catastrophic) fatigue failures. Second, the proper development of S&T products assures that they can be affordably incorporated into systems. "Proper development" includes the near-term transition, when appropriate, of S&T innovations that may reduce system cost and meet system needs "in-time", and the routine use of S&T development processes that treat life cycle system costs as a parameter equal in importance to system performance.

The DoD has been challenged to make weapons systems more producible and affordable with good planning from technology to acquisition to product manufacture. For systems already in the "pipeline", that is, mature in the design process, affordability can be achieved via upgrades to existing designs. For systems with designs not yet finalized, affordability may be achieved by addressing producibility and manufacturability as part of the S&T design process. A concerted S&T affordability effort is important to achieve reasonable acquisition and life-cycle costs.

The S&T community must not forgo the legacy of providing the 'seed-corn' for future systems but must incorporate the lessons of commercial industry. In every technological endeavor, the researcher makes 'choices' that eventually affect the utility and supportability of the final product. Commercial success has focused on developing an understanding of the effect of such choices. Stifling creativity is not the goal; providing an understanding of the long-range impact of 'choices' is.

1.3 Scope of the Handbook. This handbook provides guidelines on how to make an S&T program more affordable. The earlier we address affordability in a technology development program, the more effectively we influence the life cycle costs, and hence the affordability of products for insertion into military systems. This handbook is aimed at those S&T managers who are developing advanced technology (6.3) that may be transitioned in the near term; however, it describes how 6.1/6.2 managers may also consider affordability and be aware of systems needs in a way that does not inhibit innovation or research. This handbook is a guide for all S&T managers and focuses on the ideas, best practices, and tools in considering affordability in S&T programs. S&T affordability best practices are outlined that focus on technology transition as the way to achieve affordability. Examples of S&T affordability program case studies are provided that show how the customer – the DoD system program office or systems integrator – is involved in the development and transition of technology across one or more military systems.

1.4 Structure of the Handbook.

- **Section 2** provides guidance for S&T program managers in addressing affordability in their programs.
- **Section 3** describes some S&T affordability program case studies that are good examples of affordability "best practices".
- **Section 4** provides an overview of selected tools that can be used by program managers and their staffs in addressing affordability.

- **Section 5** lists references for additional information.
- **Appendix A** is a glossary of terms and definitions of affordability.
- **Appendix B** provides more detailed information on the tools presented in Section 4.
- **Appendix C** discusses and lists the affordability programs.
- **Appendix D** lists some of the training and educational courses that will help program staff members successfully address affordability during S&T.

2.0 GUIDELINES FOR IMPLEMENTING AFFORDABILITY PRACTICES IN R&D AND MANUFACTURING

2.1 Introduction. Historically, the focus of the DoD S&T program was to develop technology to meet future threats. The technology did not necessarily meet a warfighter requirement or get incorporated into a weapon system. However, over the past ten years, the DoD, with Congressional support, has chosen a budget strategy in which S&T funding has remained essentially unchanged while acquisition funding has decreased about 50%. With these declining DoD budgets, the trend of S&T development for the sake of purely establishing a large technology base is changing. Increasingly, S&T programs (especially 6.3 advanced technology) are developing technology with a view toward meeting nearer term warfighter requirements. It is now clear that S&T projects, especially those involving the maturation of technology for transition to existing and future systems, must clearly embrace affordability principles early in development.

Affordability must now be a consideration in the formulation of every S&T project. It is a fundamental requirement for all 6.3 projects expected to transition to demonstration/validation or engineering and manufacturing development. As stated by the Under Secretary of Defense (Acquisition & Technology) in an August 7, 1996 policy memorandum:

> Basic Research (6.1) and Applied Research (6.2) programs explore the boundaries of technology relatively unfettered by the demands of near term application, but program managers should still be aware of downstream affordability issues. Advanced Technology Development (6.3) programs must, however, address affordability issues to the maximum extent practicable to facilitate their successful and cost effective transition to the appropriate phase of acquisition.

In managing any S&T program there are a set of best practices and procedures for program management to ensure that affordability is implemented in the program. These principles are particularly pertinent to those S&T managers who are developing advanced technology (6.3) that may be transitioned in the near term. However, 6.1/6.2 managers should also be aware of these principles when managing their S&T program. These best practices and procedures are summarized below.

2.2 Affordability Best Practices and Procedures. The following affordability elements are Best Practices and Procedures captured in the form of criteria for S&T managers to address affordability in their S&T efforts. While aimed at 6.3 S&T managers, these practices and procedures are intended to help all S&T managers – including 6.1/6.2 managers – to focus on affordability in their programs without stifling creativity or innovation. These criteria are endorsed by the Deputy Under Secretary of Defense for Acquisition & Technology (DUSD/S&T) Affordability Task Force that was chartered by the Director for Defense Research & Engineering (DDR&E) in May 1995 to develop solutions on how to strengthen the affordability focus of DoD S&T programs.

2.2.1 Obtain Management Support to Meet Affordability Goals. It is the goal of the DoD to implement Integrated Product and Process Development (IPPD) methods throughout all 6.3 S&T

programs. IPPD is a management process that integrates all activities from product concept through production/field support, using multi-functional teams, to simultaneously optimize the product and its manufacturing and sustainment processes to meet cost and performance objectives. IPPD requires a fundamental shift from traditional sequential technology development to a concurrent process. Traditionally, separate groups operating independently, designed a product, then gave it to the manufacturing department. The manufacturing engineers decided that it could not be manufactured without design modifications, so they gave it back to design, and so on. Once produced, the product moved into the logistics cycle where engineers determined that it could not be supported. The goal of IPPD is to anticipate and address these manufacturing and support issues from the outset, during early design. The purpose is to ensure that "customer" requirements are addressed during the technology development process.

Management commitment to IPPD begins with understanding the IPPD process and providing funding (i.e., training/travel) to implement affordability goals by using IPPD. The commitment continues with management empowerment of Integrated Product Teams (IPTs)—cross-functional, multidisciplinary teams that facilitate transition – and possible leveraging of other related S&T programs, acquisition investments and commercial technology programs. The criteria for a successful IPPD approach are to:

a) Understand and encourage the need for a shift from a performance-only development focus to an integrated view that addresses producibility, life-cycle cost, and implementation risk along with performance.

b) Adjust the funding profile to implement affordability goals by addressing issues such as producibility, life-cycle cost, implementation risk, application of open systems, and interoperability.

c) Establish leverage with other S&T programs, acquisition investments, and/or commercial technology programs.

d) Hold technical program reviews with senior management to routinely address affordability issues.

Effective top-level management should motivate managers and workers at every level to perform as desired by clearly identifying objectives and by fostering a positive "can-do" attitude from top to bottom. Promotion policies, awards, and other formal recognition are important in providing feedback that jobs have indeed been done well. The best incentive for government managers is an environment that promotes goal setting, teamwork, and recognition of accomplishments from the management chain.

2.2.2 Implement the IPPD Methodology. More affordable technology will be achieved when IPPD methods are applied during S&T. An S&T IPT – or multidisciplinary team that includes the "warfighter" customer – is a critical component of IPPD in that life cycle and support issues are considered early in the design process. If the IPT is successful, the result will be a more mature technology that requires fewer costly changes later in the product development process. A successful

IPT achieves the benefit of reduced cost and schedule while maintaining and often increasing the quality of a technology. As industry experience has demonstrated, quality tends to cost less in the long run although the initial cost of high quality technology may be high. The same is true in S&T. IPT activities during 6.3 and advanced technology demonstrations should focus principally on the warfighter customer and meeting that customer's need. Laboratory and technology base customer needs should not be neglected, particularly in 6.2 and early 6.3 efforts. Accurately understanding the various levels of user needs and establishing realistic requirements that will enable the technology to transition smoothly into the acquisition cycle is critical to achieving affordable technology.

Criteria for developing a good IPT include:

a) Establish a multi-disciplinary team with common objectives that includes stakeholders from all government and industry elements – research, development, design, test, manufacture, training, logistics, warfighter, financial, and contracts.
b) Create a charter that clearly articulates team objectives, the scope, process approach, and individual team roles and assignments. Note that some members will attend all meetings of the IPT and will form the core team while others will meet intermittently, as required.
c) Empower members of the IPT to make decisions, and have a clear understanding on the extent of their decision-making authority.
d) Organize the team hierarchically as required. Most large projects employ a leadership or system-level IPT and a number of sub-IPTs. Leaders of sub-IPTs are members of the leadership or system-level IPT.
e) Keep IPTs relatively small, generally seven members or fewer, and not more than nine. "Real work" rarely gets accomplished with ten or more individuals present.
f) Assign strong, senior leaders to the IPT and sub-IPTs. IPT and sub-IPT leaders must be able to work well with teams, understand group dynamics, and possess sufficient technical depth to properly track progress and report accurately on activities. The IPT goal is consensus; the IPT leader's task is to facilitate the achievement of this goal.
g) Put in place a mechanism to document and track assignments, action items and workflow among the team members and establish effective communication processes between IPT members. This mechanism and communications can be a simple email-based process or a more sophisticated web-enabled workflow tool.
h) Implement regular sessions and a reporting process, so that work in process is tracked regularly and team members are regularly accountable for their contributions to the team.
i) Use contract incentives and requirements to incentivize affordability.

Successful S&T managers have used industry contract incentives to encourage affordability. Contractually incorporating production and life-cycle cost objectives and providing for a sharing of the savings when costs come in below objectives creates a "win-win" situation for all. Well-structured contracts and well-designed contract incentive clauses are key in focusing contractor attention on cost reduction. Cost plus incentive fee contracts have been shown to be a good method of achieving affordability.

2.2.3 Develop and Execute a Training Plan. IPPD is an excellent method to systematically manage priorities, performance, cost and risk. In particular, when applied to the 6.3 environment, IPPD methods can assist in effectively transitioning technology. However, for IPPDs to be effective, S&T personnel must have the skills, knowledge, motivation and the environment to make it happen. A culture change through education and training in affordability principles is essential to modify the long standing S&T focus on performance.

Proper training for IPTs is an important ingredient for success. The three criteria related to preparing a training plan are to:

a) Conduct training as a team, including training of the industry partners and warfighters.
b) Conduct IPPD tool training, e.g., group dynamics, quality function deployment, six sigma, design of experiments.
c) Identify funding and set aside funding to conduct training.
d) Provide for future training as the needs exist.

Appendix E provides a listing of various training classes that are available to S&T managers.

2.2.4 Establish and Track Affordability Metrics. An S&T program manager needs to establish quantitative metrics by which to track the progress of an S&T program. By applying and tracking performance and programmatic metrics, an S&T manager can identify actions and resources needed to successfully satisfy requirements. The criteria for establishing metrics are the following:

a) Identify quantitative metrics – programmatic and technical – in order to measure affordability.
b) Develop key exit criteria for transition.
c) Demonstrate and validate the cost/benefit of the technology (e.g., through modeling and simulation).
d) Adopt best practices and benchmarking activities.
e) Measure and report metrics periodically.

In general, metrics should be simple, related to the team's or organization's goals, and be meaningful to both the team and the customers. In some cases, technical performance should be measured, in others programmatics. In most cases it is both. Understanding what is important for the team's success, and to the customer is critical. It is imperative that identification of the metrics be done in coordination with the customer.

Examples of programmatic measures are unit cost, operating and support cost, or life cycle cost savings/avoidance and leadtime reduction savings. These may be measured using cost and schedule reporting data such as Schedule and Cost Performance Indexes (SPI and CPI) and Schedule and Cost Variance (SV and CV). Technical reports can be examined to see what measures of the performance and process characteristics may be used as technical metrics. These data should be highlighted and tracked closely. New metrics should be selected only as needed to supplement existing information.

Metrics that do not effectively measure progress should be eliminated in lieu of more meaningful measures. Each IPT needs to establish the set of metrics that is most appropriate to their product.

In addition to programmatic and technical metrics, the IPT needs to establish key exit criteria for affordable transition of the S&T technology to a weapon system(s). It should be noted that most exit criteria include the requirement to deliver the technology according to a specified schedule. S&T program exit criteria for transition to DoD systems may consider the following:

a) Technological performance requirement of system (e.g., lighter, stronger, more resistant to environmental stresses, faster, and smaller).

b) Need for cost effective manufacturing processes to reduce system cost.

c) DoD need for common hardware across multiple systems (e.g., open systems approach).

d) The requirement for technology applications, as defined by the Defense Technology Area Plan or Joint Warfighting S&T Plan.

e) Form-fit-function replacement for block improvement of existing subsystem.

f) Alternative technology approach required to improve producibility/lower project cost (e.g., less expensive, more durable composite part to replace an aluminum part) while system design is still flexible (i.e., in engineering and manufacturing development or EMD).

g) Meets critical shortfalls in which an unanticipated pre-or-post EMD problem may seriously affect deployment/use of the system after deployment.

h) Weapon system program office wants the technology and is financially supportive of inserting the technology into their system or has executed a Memorandum of Understanding (MOU) with the S&T program office.

2.2.5 Develop a Transition Plan. With the continued consolidation of the Defense industry, and with DoD under continued pressure to acquire and sustain more affordable DoD systems, the successful transition of technology into acquisition and the sustainment of those weapons systems has become a critical issue. All S&T managers should be aware of near term transition opportunities for their technology and 6.3 managers, in particular, must facilitate successful and cost effective transition of their technology to needed systems/subsystems. While it is true that the primary goal of S&T is to develop and demonstrate technology, process maturity of a technology must be understood during S&T so that technical and economic risks associated with technology transition may be reduced. In addition, it is also necessary to be able to know when and how to "market" a technology that is ready for insertion. Some criteria for the successful transition of an S&T program are to:

a) Establish and maintain frequent communication with Warfighter and Acquisition Customer.
b) Work together with the warfighter, acquisition customer and contractor on an Integrated Product/Process Team (IPT)
c) All stakeholders understand and agree to the end product of the S&T program
d) Put in place MOAs, MOUs, or other written agreements to demonstrate a commitment by all parties to implement the technology results
e) Establish a Transition Team at the beginning of the S&T program

f) Develop a formal Transition Plan
g) Understand the Warfighter and Acquisition Customer requirements
h) Put a funding strategy in place to effect transition

One of the most important aspects in transitioning the results of an S&T program is to prepare a written transition plan or commitment between the S&T program manager and the customer to implement the technology results of an S&T program. Elements of a good transition plan are the following:

- Technology development outline
- Expected outcomes of S&T project
- S&T funding strategy
- Schedule/milestones/when technology is ready to be handed over
- Identification of customer
- Acquisition strategy/integration plan
- S&T issues/risks – technical, production or logistics
- Signed "customer" and S&T manager commitment
- "Customer" funding strategy to implement technology
- Leveraging/linkage/related technologies (i.e., DTAP/JWSTP)

Overall, the elements of a successful S&T transition include early identification of customer needs, formal program office support (with MOU, IPPD, and transition plan), development of affordability metrics against which to track progress, and addressing producibility and sustainability throughout the S&T program.

An S&T transition model (see Figure 2-1) has been developed that addresses two specific aspects of the overall issue in transitioning the result of 6.3 S&T programs: (1) identification of best practices and actions that can be taken by S&T program managers under current policy and procedures; and (2) identification of management issues that are at a policy level requiring action by management above S&T.

The implicit message in the model above is that a disciplined process is needed that is clearly driven by requirements. The intent is to ensure that funding priorities are appropriately based on these requirements and that senior management reviews project funding if requirements are unlikely to be met. The model illustrates the desired multi-community team approach and includes the need for metrics on all aspects of transition. Key to the successful implementation of this model is the need to provide incentives to S&T personnel to achieve transition.

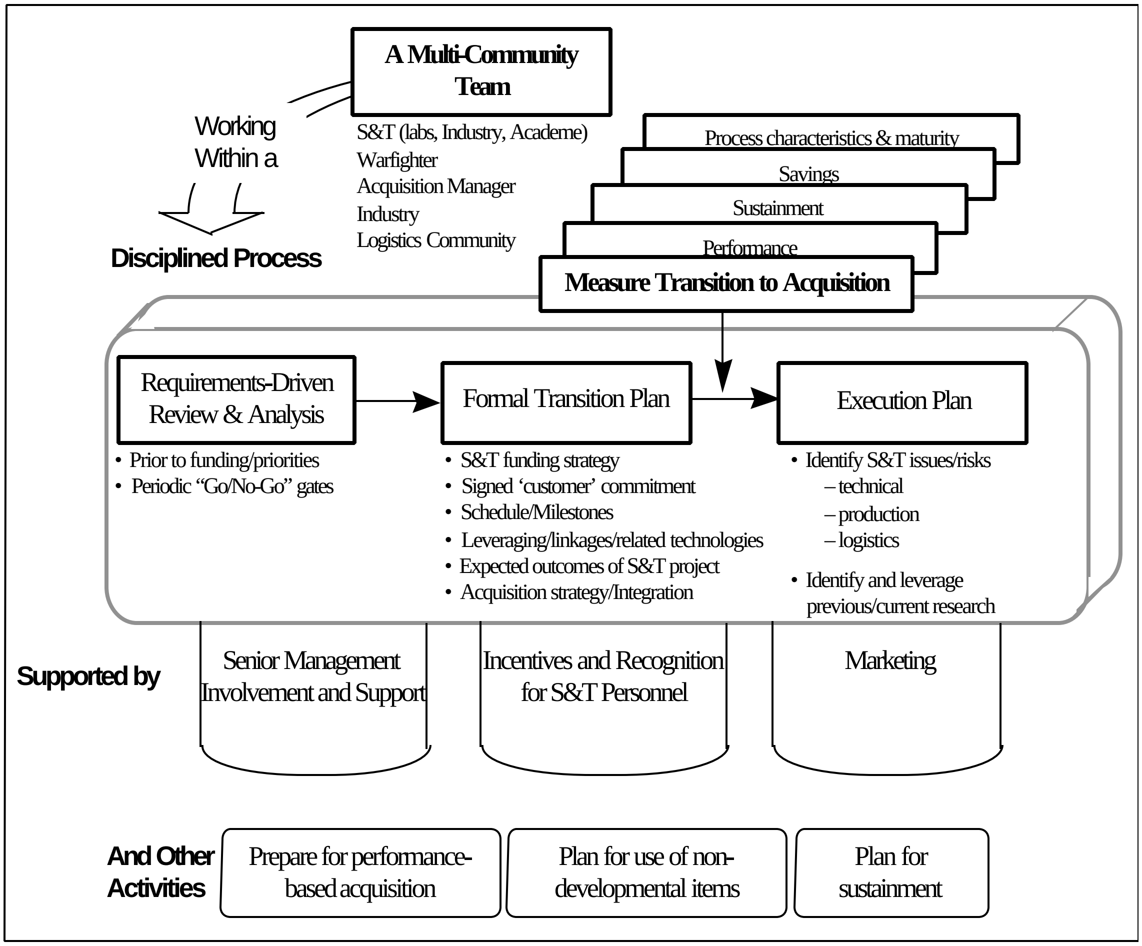

Figure 2-1. Model for transitioning the results of 6.3 S&T programs.

There are four key considerations in implementing the transition model:

1. The assessment of S&T personnel should be based on transition and affordability in addition to technical achievements, papers, etc.
2. S&T personnel must take the initiative to be more customer-oriented. They must clearly understand the customer's needs with the requirement that 6.3 efforts be 'pulled' by those needs. Communication and marketing of the S&T project effort and results is essential.
3. S&T Program Managers must understand acquisition and requirements communities (and vice-versa). The career path to S&T program management should consider 'exposure' to both communities. For example, S&T Program Managers should have knowledge of available technologies and 'marketing' skills; should periodically "participate" in field activities; and should be periodically co-located with the acquisition program.
4. Acquisition management should be involved in S&T (6.3) funding decisions. A real commitment should be obtained from acquisition managers to transition the technology.

2.2.6 S&T Affordability Task Force Reviews. The S&T Affordability Task Force annually reviews select “affordability programs” that are submitted by tri-Service/DARPA members of the task force. These affordability programs are evaluated by their compliance with the affordability criteria listed in Sections 2.2.1 – 2.2.5 above. Some affordability programs receive very high scores because the programs notably emphasize near term (within 3-4 years) technology transition. This near term transition is evidenced by specific transition plans, POM funding that is budgeted by the user (i.e., system to which technology is to be transitioned), or active user involvement in the planning of the technology program. Some notable examples of highly rated projects are summarized below as case studies.

3.0 SCIENCE AND TECHNOLOGY AFFORDABILITY CASE STUDIES

In 1995, the Director for Defense Research and Engineering tasked the S&T Affordability Task Force (ATF) to screen S&T programs for affordability content and to develop a methodology to address process maturity earlier in acquisition programs – namely at the S&T development stage. On an annual basis, fifteen to twenty affordability programs are identified by the military departments and DARPA and evaluated on how well they meet the defined affordability criteria (described in Section 2). The Affordability Programs represent S&T projects from many different technology areas as identified in the annual Defense Technology Area Plan. The results of the ATF review are summarized to the Defense Science & Technology Advisory Group (DSTAG). A listing and brief description of S&T Affordability Programs reviewed through 1999 is found in Appendix D.

This section outlines some of the highest rated affordability programs that serve as examples of S&T case studies on affordability best practices in that they focus on customer involvement and on transition of the technology into a system. The customer – that is, the DoD program office or systems integrator – is involved early-on in planning the transition of technology across one or more military systems. Elements of the technology transition process described in Section 2.2.5 are prevalent throughout these examples – customer needs are identified early, customer management support is formalized with transition plans, affordability metrics are established against which program progress is measured, and producibility and manufacturing issues are addressed throughout the program. A number of these affordability programs have been presented at various affordability workshops and conference as “best practice” examples of affordability.

3.1 Composite Armored Vehicle Advanced Technology Demonstration (CAV ATD). The CAV ATD was one of several S&T programs that may provide opportunities for more deployable combat systems. The CAV ATD program was a key element of the Army's effort to develop lighter, more deployable and survivable ground combat vehicles. It focused on demonstrating the technical feasibility and operational potential of composite materials for vehicle hull structure and armor. The program addressed such issues as resistance to high and low velocity impact, damage tolerance, repairability, affordability, structural integrity (durability), non-destructive inspection, structural integration of signature and armor, scalability, and manufacturing methods and technology which must be solved before composites can transition to ground combat systems. The program's 22-ton demonstrator was durability tested for 6,000 miles and tested with a 105-mm cannon to evaluate the high gun firing forces imposed by a heavy, direct fire weapon on its composite hull.

CAV ATD was designed to support the development of future lighter weight vehicles with at least a 33 percent reduction in hull structure and armor weight and with reduced development time, costs and risks. The program supported potential options for multiple future systems such as the Future Scout Vehicle or Future Tank and follow-on upgrades to fielded systems.

The Army awarded the CAV ATD contract to the United Defense LP in December 1993 to design and fabricate a technology demonstrator and modeling and simulation validation. The technology demonstration concluded in fiscal year 1997.

The CAV ATD contract did not require Integrated Product Process Development (IPPD) implementation at the time of its award, however, it did require a management system that would utilize the concept of concurrent engineering. It also required the application of Six Sigma methodologies at a level suitable for an ATD throughout duration of the program. Shortly thereafter, it became clear to the Army management that a more comprehensive IPPD approach was needed for the CAV ATD program to become a model for IPPD implementation in other future Army programs. Through a benchmarking process, a tailored Texas Instruments IPPD methodology and the Motorola Six Sigma approach to quality were adopted, licensed and implemented by formal training of both Government and Industry team members. The CAV ATD was one of the first S&T programs to implement the IPPD process to assure that concurrent engineering and Government/Industry teaming were incorporated early on in program to maximize influence on design cost, quality and producibility. Based on direction by senior Army S&T leadership, the United Defense LP and the Army's Tank-Automotive Research, Development & Engineering Center (TARDEC) embraced the IPPD process and are now using it on other Army ground combat development programs.

Technology developed for CAV has transitioned to the Crusader acquisition program. One of the virtues of CAV as a vehicle demonstrator was that it addressed a range or variety of ballistic threats and produced a virtual menu of proven solutions for future vehicle designers. The CAV aft upper hull most nearly matched the Crusader SPH turret shell and RSV mission equipment structure ballistic requirements, and therefore was readily applied with only slight modification.
CAV’s emphasis on affordability resulted in ceramic armor selections that transitioned directly to Crusader. This affordability-based approach was critical to successful transition in that the technology did not exceed Crusaders’ unit-cost premium for weight-reduction technologies. CAV’s emphasis on the Automated Fiber Placement (AFP) process will not likely transition to Crusader. Yet lower cost, less capitol intensive, high thru-put processing technology such as Vacuum-Assisted Resin Transfer Molding (VARTM) will most likely be the process of choice for ground vehicle production.

A focused manufacturing technology program is now bridging the gap between the ATD and Crusader production with a goal of cost-equivalence with the aluminum baseline in rate production for composite ballistic structures.

Point of Contact: Jamie Florence (810) 574-7639

3.2 Generation II Soldier (Next Generation Soldier ATD). The GEN II ATD was the cornerstone program of the 21st Century Land Warrior (21 CLW) Integrated Technology Program (ITP). It addressed future dismounted soldiers as a system and as a weapons platform, with the purpose of enhancing the individual soldier’s survivability, lethality, mobility, and situational awareness. The GEN II ATD accomplished these tasks by improving upon current dismounted soldier capabilities, while reducing the size, weight, bulk and power requirements relative to current equipment, as well as by providing new capabilities previously unavailable to dismounted soldiers. The GEN II program met these goals through a fully integrated systems development approach that stressed modularity, interoperability, and soldier compatibility.

The program consisted of five subsystems: 1) the Integrated Headgear Subsystem (IHS) with a helmet mounted display, head orientation sensor, helmet mounted mobility sensor and improved ballistic protection; 2) the Individual Soldier Computer/Radio (ISCR), a 2.5 pound Power PC based computer radio with 1.3 to 5 km range, integrated GPS and POSNAV navigation systems and expansion/interface capabilities to accommodate other 21 CLW components; 3) the Protective Subsystem (PS), an enhanced lightweight body armor, totally new load carrying equipment with embedded ISCR and IPS components, and enhanced uniform components; 4) the Weapons Interface Subsystem (WIS), which provides the link between the ISCR and the various future weapons being developed for dismounted soldiers, such as the Javelin and OICW, and 5) the Interface and Power Subsystem (IPS), which is responsible for managing the power budget, locating connectors and wiring, and determining battery requirements and trade-offs.

The GEN II system was awarded in August 1994 with Motorola as the prime contractor and Hughes, Gentex, Battelle, Honeywell, and Arthur D. Little as contractor team members. The GEN II office of Natick RD&E Center, Soldier Systems Command led the development effort and worked in conjunction with US Army CECOM, ARDEC, DARPA, ARL and other government agencies.

The GEN II ATD was structured with IPPD as a primary characteristic of the program. The use of IPPD and IPTs was a key evaluation factor during the source selection for the program and insured that IPPD is inherent in all management and technical aspects of the program. The GEN II team had a strong customer focus and worked in conjunction with the Army's Dismounted Battlespace Battle Lab and the USMC to ensure user participation. The program was notable for its military members' involvement in the planning from the beginning of the design process to the system integration through the User Systems Engineering Requirements (USER) Panel. The panel members were involved in frequent system and component assessments and were on hand to provide immediate feedback to engineers and designers. The GEN II program further facilitated customer/contractor interaction by sponsoring a USER representative and government technical representative at the contractor's facilities. IPPD was further implemented on the GEN II program through formal IPPD/IPT training with Motorola University for all government and civilian personnel. IPPD concepts were fully embraced by senior Army leadership across all organizations, and the philosophy of investing in affordability and producibility issues early on in product development was proliferated throughout the program. Metrics were used to track affordability and producibility issues, i.e. Design to Unit Production Cost (DTUPC), Six Sigma, and to track program progress so that problems could be seen on the horizon, allowing for their timely management.

The GEN II ATD, and the associated technology applications, transitioned from the S&T community to the Land Warrior acquisition program beginning in 1996. The IPPD/IPT approach enabled many technologies from the GEN II ATD to be rapidly incorporated into the Land Warrior program. A Technology Insertion IPT was chartered with participation from government and contractor personnel from both the GEN II ATD and the Land Warrior acquisition program to enhance the transition process. Contract modifications were required for both prime contracts to execute these transitions. Examples of successful transitions include an integrated helmet suspension, liner and communications headset assembly, active matrix electro-luminescent (AMEL) head mounted display, low power display driver electronics, integrated GPS module,. dead reckoning module, selected Graphic User Interface (GUI) software, and system voice control. Each technology was measured against performance exit criteria and USER Panel ratings before being considered for transition. Once the technology passed through those “gates”, then the technology designs, prototypes, technical reports, test reports, and any lessons learned were provided to the Land Warrior IPTs through a series of technical interchange meetings. In some cases the same contractor personnel who worked on the GEN II ATD team “transitioned” with the technology and became members of the appropriate Land Warrior IPTs.

POC for this program is Mr. John Munroe, (508) 233-5813

3.3 Advanced Enclosed Mast/Sensor (AEM/S) System. The U.S. Navy, through the Office of Naval Research (ONR), is the primary sponsor of the AEM/S System, a DoD Affordability Program. The U.S. Navy’s first-ever advanced hybrid composite structure has been installed aboard the Spruance Class multi-mission destroyer USS ARTHUR W. RADFORD (DD 968) at Norfolk Naval Shipyard, Portsmouth, Virginia. The ship will be the platform for extensive testing of the new mast by the Navy. The AEM/S System mast was installed aboard the RADFORD to replace her conventional main (aft) mast. The RADFORD, currently undergoing regular overhaul, will return to normal fleet service in Fiscal Year ‘98 with a fully operational AEM/S System. The AEM/S System will remain aboard the RADFORD for at least a year of tests and at-sea trials.

The AEM/S System is a 93 foot high, hexagonal structure, 35 feet in diameter, enclosing existing radars and providing important signature and other operational benefits. By enclosing major antennas and other sensitive equipment, the AEM/S System protects them from the weather. This reduces maintenance, as well as providing significantly reduced radar signature. The new, advanced composite mast, which the Navy describes as "revolutionary and spectacular," was built and designed by an Integrated Product Team (IPT) -- known as "The AE MIS System Masters" -- made up of technical experts drawn from diverse Navy and industry activities nationwide.

As an Affordability Program, the AEM/S System ATD has developed a revolutionary mast that is affordable, solves problems associated with current masts, enables new technology required for the Navy's next generation of stealthy ships, reduces life-cycle costs, enhances sustainability, and most importantly, enhances war-fighting capabilities. Successful completion of this ATD is a key element in the incorporation of advanced technology into the topside design for the next generation of surface combatants.

Participating in the development, design, and construction of the AEM/S System were representatives of the Office of Naval Research, Naval Sea Systems Command, Naval Research Laboratory, Carderock and Dahlgren Divisions of the Naval Surface Warfare Center, Naval Command and Control and Ocean Surveillance Center, and Norfolk Naval Shipyard. Industry participants were Ingalls Shipbuilding, Seemann Composites, Mission Research Corporation, Material Sciences Corporation, Ohio State University, and Analysis & Technology.

The AEM/S System is a high-risk, high-payoff ATD. Benefits and payoffs include:

- Enhanced Performance. The AEM/S System is fabricated with an advanced composite hybrid Frequency Selective Surface (FSS), designed to allow passage of own-ship sensor frequencies while reflecting other frequencies. Improved sensor performance results from reduction of blockage, false targets and sensor downtime, thereby dramatically enhancing the ship's war-fighting capability.

- Affordable Low-Cost Manufacturing. AEM/S utilizes unique materials, creative structures and innovative manufacturing techniques, yet the mast can be produced in a shipyard.

- Affordable Reduced Life-Cycle Costs. The AEM/S System's enclosed structure protects radars and communication antennas from weather exposure and provides all-weather access for repair, thus greatly reducing the need for repair, maintenance costs, replacement costs and risk of failure.

- Enhanced sustainability. The AEM/S System concept will enable rapid and seamless transition to the next generation of technology. Features such as embedded sensors, planar arrays, integrated antennas, low observable signatures, reduced topside weight -- all contribute to the Navy's objectives for future warships. Accelerated transition of AEM/S System technology to the LPD 17 is already underway, along with evaluation of its applicability to the SC 21 and CV(X).

- The upper half of the AEM/S System is designed to allow passage of own-ship sensor frequencies with very low loss while reflecting other frequencies. It is divided into two radome-like compartments; the upper compartment houses the MK 23 TAS antenna, and the lower encloses the SPSAO air search radar antenna.

The whole system is a free-standing, fully integrated composite structure. Structural design requirements for strength and stiffness meet Fleet requirements for vibration, shock and fatigue.
Signature and electromagnetic design requirements are based on criteria associated with sensor and antenna performance, electromagnetic interference, lighting protection electromagnetic shielding, electrical bonding and grounding. As noted by the S&T Program Manager, “the objective of this team effort was to develop an affordable mast by fully integrating sensor technology, electromagnetics, signature reduction, advanced materials structures and manufacturing technologies. The AEM/S System will result in significant new design options for both future surface ships and major upgrades. This program is a necessary step in the development and deployment of next generation radar and communication systems."

POC for this program is Jeffrey L. Benson, NSWC, White Oak, 301-227-1087.

3.4 Miniature Air Launched Decoy (MALD) Program. The goal of the MALD Advanced Concept Technology Demonstration (ACTD) is to develop and demonstrate a small, very inexpensive air-launched decoy system for the Suppression of Enemy Air Defenses (SEAD) mission. Current decoys are large and expensive, and most lack the range, maneuverability, and speed needed to accurately simulate combat aircraft. MALD will greatly enhance the survivability of friendly aircraft and aid in establishing air superiority by stimulating, diluting, and confusing enemy integrated air defense systems. The MALD is a small, affordable, jet-powered Unmanned Air Vehicle (UAV) that will appear electronically to be a larger aircraft. When launched from platforms such as the F-15, F-16, and US Navy F/A-18, the MALD will confuse enemy air defenses by simulating aircraft attacks against early warning radars. It will also cause missile fire control systems to target the decoys rather than friendly aircraft and, by saturating enemy air space with sufficient multiple simulated targets, significantly degrade the enemy's ability to find and track actual aircraft.

As an affordability program reviewed by the ATF in 1997 and 1998, notable affordability best practices include the following:

- Performance and cost tradeoffs have been carefully considered (using the CAIV process) throughout the program. For example, a MIL STD that required -95° operation on 3% of the days in a year was canceled by the user because the design to reach this standard would have been very expensive at a temperature that is rarely encountered; and the payload antenna was reduced.
- Commercial processes: Use of COTS parts, with a reliability factor of 95%. The composite fuselage is to be built at the Ford pickup truck production facility, with the commercial manufacturing processes only slightly altered to mold the part.
- Strong use of teaming/IPTs: Teledyne Ryan leads the transition IPT that includes the warfighter, industry, DARPA, AF ASC, user, and the Air National Guard.
- Transition of the development and acquisition of MALD from DARPA to the Air Force will be facilitated by the ACTD. ACC is the designated user and is responsible for assessing military utility and developing the employment tactics for the MALD system. The Air National Guard, the Operational Test Agency for the ACTD, will provide all support necessary to conduct and evaluate flight testing. When the ACTD ends, 32 residual MALD systems will be turned over to ACC for further testing, tactics development, or possible limited operational use. If ACC determines that MALD offers sufficient operational utility to warrant procurement, the Air Force may elect to start low rate production with an inventory objective of 1500 units. The U.S. Navy is also a potential user of MALD.
- Incentives: Use of award fee to motivate contractor to meet unit price objectives.

The MALD is being developed in response to an Air Force Air Combat Command (ACC) requirement for an aerial radar decoy. The affordability objective is to build a miniature air vehicle that mimics aircraft or weapons with a $30K average unit fly away cost goal at unit 3,000. The Air Force F16 is the vehicle in which the technology is to be demonstrated. DARPA is presently working with the Air Force Aeronautical Systems Center (ASC) as its agent, to conduct an ACTD of an inexpensive miniature air-launched decoy. Teledyne-Ryan, the prime contractor, will design, build and test complete MALD systems, including the signature-enhancement payload package; conduct producibility analysis and planning; and develop concepts of operations and tactics refinement.

POC for this program is Walt Price, DARPA/TTO, (703) 696-7500.

4.0 OVERVIEW OF SELECTED AFFORDABILITY MANAGEMENT TOOLS

This section provides general information on some of the more significant tools and techniques available to support managers in meeting affordability goals. These tools and techniques are:

- Integrated Product and Process Development (IPPD)
- Integrated Product Teams (IPTs)
- Quality Function Deployment (QFD)
- Design of Experiments (DOE)
- Design for Six-Sigma
- Cost as an Independent Variable (CAIV)
- Modeling and Simulation

A more detailed discussion of each of these tools is provided in Appendix B and in the designated references in Section 5. These are not the only tools available for program implementation, but do reflect the techniques most often applied in acquisition and best practice affordability programs.

4.1 Integrated Product and Process Development (IPPD). IPPD is a management technique that simultaneously integrates all essential acquisition activities through the use of multi-disciplinary teams to optimize the design, manufacturing, business, and supportability processes. IPPD has its roots in integrated design and production practices, concurrent engineering, and total quality management. In the early 1980s, U.S. industry used the concept of integrated design as a way to improve global competitiveness.

DoD defines IPPD as, "A management process that integrates all activities from product concept through production/field support, using a multi-functional team, to simultaneously optimize the product and its manufacturing and sustainment processes to meet cost and performance objectives." (See DoD IPPD Web Site. http://www.acq.osd.mil/sa/se/index.htm).
IPPD evolved from concurrent engineering, and is sometimes called integrated product development (IPD). It is a systems engineering process integrated with sound business practices and common sense decision making. Organizations may undergo profound changes in culture and processes to successfully implement IPPD.

IPPD activities focus on the customer and meeting the customer's need. In DoD, the customer is the user. Accurately understanding the various levels of users' needs and establishing realistic requirements early in the acquisition cycle is now more important than ever. Trade-off analyses are made among design, performance, production, support, cost, and operational needs to optimize the system (product or service) over its life cycle. In order to afford sufficient numbers of technologically up-to-date systems, cost is a critical component of DoD system optimization. Cost should not simply be an outcome as has often been the case in the past. Thus, cost should become an independent rather than dependent variable in meeting the user's needs.

4.1.1 An S&T IPPD Process

Over the past two years, the Air Force Research Laboratory has conducted pioneering work in how to implement IPPD in an S&T environment. While many of the IPPD practices implemented in the weapons systems acquisition environment apply to S&T programs, it became clear to senior Air Force S&T executives these practices needed to be tailored for design and development programs. This section describes the Air Force process for applying IPPD on S&T programs. The basic functions associated with implementing IPPD principles are the following:

(1) Determine requirements;
(2) Establish S&T exit criteria;
(3) Develop technology alternatives;
(4) Perform value analysis;
(5) Develop and demonstrate technology; and
(6) Analyze and deliver project results.

This process illustrated in Figure 4.1 was developed by the U.S. Air Force in conjunction with approximately 30 companies in the defense aerospace industry. While the process is displayed horizontally to make it easy to read, it is *not* a serial process, as the large elliptical background

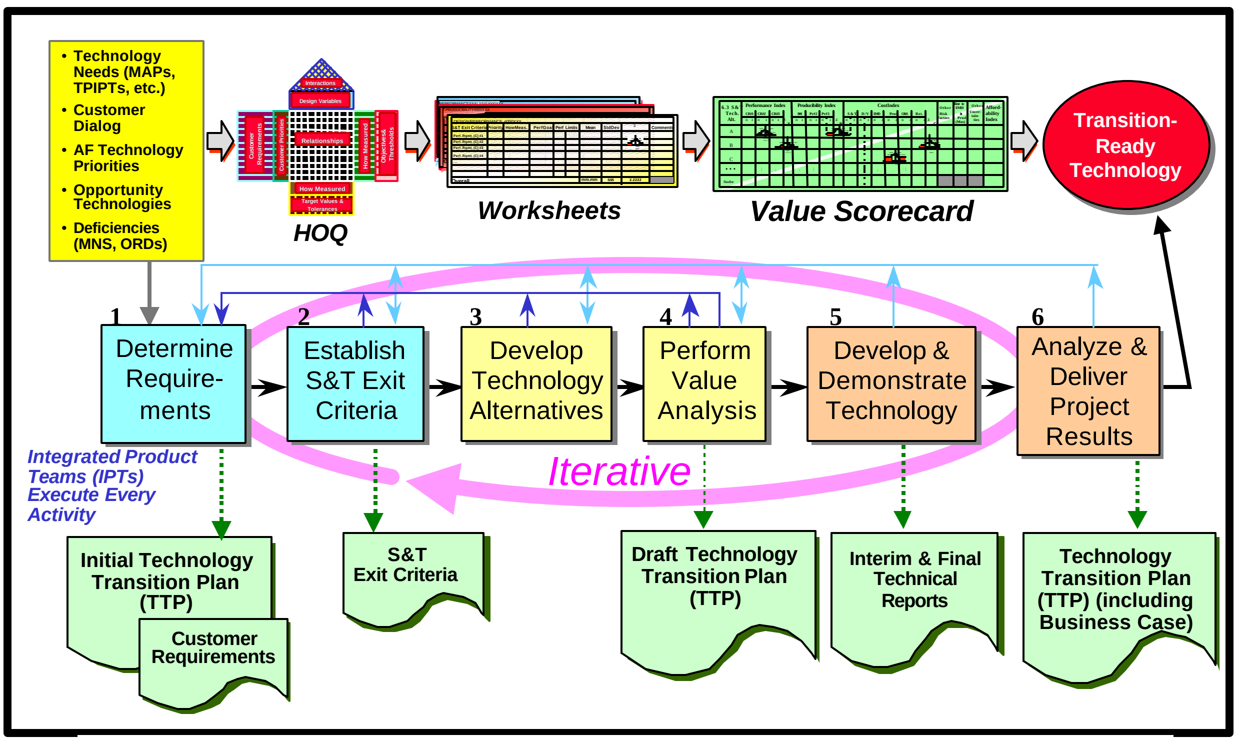

Figure 4.1. An S&T IPPD Process

arrow suggests. The key activities associated with the process are represented by the central six blocks. The document symbols along the bottom represent important outputs from the process. The artifacts along the top of the diagram represent various methods and tools that can be employed to implement the process.

During a workshop in 1994, when this process was first contemplated, it became apparent to everyone present that IPPD is not something that can be layered on top of an S&T development effort. Rather, *one either develops technology in an integration fashion, or one does not*. As that workshop, industry experience, and subsequent experience with S&T IPPD Pilot projects have all demonstrated, IPPD is *not something you do in addition to S&T*. It is a fundamental way of thinking about and executing technology development. There is not one set of program goals and another set of IPPD goals. They must be one and the same. They must address the critical issues associated with technology maturation and transition (viz. producibility, life-cycle cost and risk). It should be noted that if transition issues to the next phase of development are not addressed as explicit program requirements, the program is *not* addressing IPPD issues, regardless of the use of a team approach. The process in Figure 4.1 provides a structured approach for addressing those critical issues, namely, the balance of performance, producibility, cost and risk, and making those elements integral to an S&T effort.

The six activities outlined in the integrated technology development process are described in detail in Appendix B (Section B.9). Also, additional information on how specific methods and tools are used, as represented in the artifacts along the top of the process, are detailed in the appendix.

4.2 Integrated Product Teams (IPTs). Integrated Product Teams are cross-functional teams that are formed for the specific purpose of delivering a product for an external or internal customer. IPT members should have complementary skills and be committed to a common purpose, performance objectives, and approach for which they hold themselves mutually accountable. Members of an integrated product team represent technical, manufacturing, business, and support functions and organizations that are critical to developing, procuring and supporting the product. Having these functions represented concurrently permits teams to consider more and broader alternatives quickly, and in a broader context, enables faster and better decisions. A critical element of successful IPTs is effective communications between team members who work together to achieve the team's objectives. Additional information concerning conduct and formation of IPTs can be found at the DoD Systems Engineering website: http://www.acq.osd.mil/sa/se/index.htm).

4.3 Quality Function Deployment (QFD). Quantitative S&T development goals should be derived using the same process used to derive product requirements for specific programs. This process consists of performing a needs-analysis and uses tools such as Quality Function Deployment (QFD). QFD is a tool for translating defined customer requirements into appropriate design requirements at each stage of design and development. The method uses a matrix known as the House of Quality. This "house" encompasses several elements: *Whats, Hows, Importance, Weighted Importance, Relationships*. The following provides a definition of these terms:

Whats	The product characteristics, functions, or levels of performance wanted by the customer. These are the customer needs or requirements. The *Whats* are sometimes divided into Primary, Secondary, and Tertiary requirements. Examples of each for a fighter aircraft are, respectively, Operating Characteristics, Sorties, and 4 Sorties per Day.
Hows	The ways in which the *Whats* can possibly be met. Also called design requirements. A *How* for the fighter sortie requirement might be a product availability of 0.92
Importance	The value or importance placed by the customer on each *What*. Typically stated as Greatest, Average, or Least.
Hows to *Whats* Relationships	The relative strength of the relationship between a *What* (a requirement) and a specific How. Typically stated as Very Strong, Strong, or Weak or a corresponding numerical value.
Weighted Importance	The importance of each *How* based on either its *How* to *What* relationship value and number of tertiary *Whats* (absolute weighting) or the relationship value, risk, and number of tertiary *Whats* (relative).
How Correlation	The strength of the technical interrelationships between the *Hows*. Typically stated as Very Strong, Strong, or Weak. Often, positive and negative relationships are indicated using separate symbols.
Risk	The degree of technical and cost risk associated with each *How*. Typically stated as Greatest Average, or Least.
N	The total number of requirements (Whats).

By using successive QFD "Houses of Quality", with the *Hows* from one used as the *Whats* of the next, increasingly more detailed (lower level) requirements can be derived.

4.4 Design of Experiments (DOE). Design of Experiments (DOE) is a statistical approach to identify and improve factors that impact product performance. It consists of seven steps:

- Select the factors to be tested and parameters to be measured
- Determine the factor values to be used as test settings
- Set up the test array
- Run the tests
- Analyze the results
- Calculate optimum values for the factors
- Run confirmation tests

DOE is often used in production to determine the optimum settings for production processes. In S&T development, it can be used to optimize performance parameters and to select optimum processes for new products.

4.5 Design for Six Sigma. "Six Sigma" is the title used by Motorola for their initiative to improve their products by reducing variability. Using measures, such as the standard deviation, one can determine the proportion of the product for which the measured parameter will be between the upper and lower specified limits, and thus is acceptable. For example, if a parameter is distributed normally, 66.3% of the product will have a parameter value within plus and minus one sigma of the mean value of the parameter, 95.5% between plus and minus two sigma, and 99.7% between plus and minus three sigma. The goal of the "Six Sigma" program formulated by Motorola is for such low variability in the process that a variability of six sigma in the value of the parameter of interest will fit between the specification limits. By way of comparison, the average business process is a "four sigma" process, which translates to 6,200 items per million "out of spec." Achieving a "six sigma" process requires the control of critical process parameters, which can be identified by the statistical design of experiments, the previous topic.

Many S&T managers ask the question as to how six sigma can be applied to prototype models produced in the laboratory environment, given that historical data and trends point to application for measuring variability of systems/components in a production environment. One of the original "model" programs for affordability, the Next Generation Soldier System, provides a good example of how this tool might be applied to 6.3 ATDs:

- A sigma approach was used to estimate the sigma for production units, not developmental units. These estimates were based on historical data and/or extrapolations from historical data, for like or similar components. Utilizing the sigma approach, each unit was broken down to the smallest piece (e.g. PC board, wiring harness, etc.), an estimate of the sigma value was made on each item, and then rolled up for all components to get an overall sigma estimate for the subsystem or system. Since the NGS used historical estimates, the values had to be reviewed frequently to ascertain whether the assumptions and data used changed over time. If they did, a new sigma must be calculated. In the developmental program, the key emphasis should not be on the precise sigma value, but rather, it should be on identifying potential show stoppers, or components, which because of their complexity or manufacturing immaturity, will not allow one to achieve reasonably high sigmas in the future. When these problem components are identified, one must either try to find replacement components or develop better manufacturing processes.

4.6 Cost as an Independent Variable. DoD has adopted a new acquisition strategy to meet the future needs of our forces with highly capable systems at affordable costs and possibly shorter schedules. This strategy entails setting *aggressive*, realistic cost objectives for acquiring defense systems, and managing risks to obtain those objectives. Cost objectives must balance mission needs with projected out-year resources, taking into account existing technology as well as high-confidence maturation of new technologies. This concept has become known as "cost as an independent variable" (CAIV), meaning that once the system performance and objective cost are decided (on the basis of cost-performance tradeoffs), the acquisition process will make cost more of a constraint and less of a variable, while nonetheless obtaining the needed military capability of the system.

A major topic upon approval of a Mission Need Statement should be the approach and inputs used to set and refine cost objectives. At each milestone review, cost objectives and progress in achieving them should be assessed. There must be flexibility for adjustments and/or refinement in cost objectives. To assist in establishing program cost objectives and to facilitate cost-performance tradeoffs, the Overarching IPT (OIPT) for each Major Defense Acquisition Program is required to establish a Cost-Performance Integrated Product Team (CP-IPT). It is critical that the user community has representation on the CP-IPT. Industry representation, at the appropriate time, is also expected.

4.7 Modeling and Simulation. In recent years, advances in information technology have offered new opportunities for tools to aid the analytic and design communities. These new opportunities come from computers and communications that are much faster and affordable. Finer granularity models can be used that execute in the same elapsed time as did less precise, older models.

The new 5000-series acquisition regulations strongly encourage the use of models and simulations to improve quality and to reduce acquisition time, resources, and risks. They also encourage embedding virtual prototypes in synthetic environments to support requirements definition, concept exploration, and manufacturing and testing of new systems.

Simulation Based Acquisition (SBA) is an acquisition process supported by the robust, collaborative use of simulation technology that is integrated across acquisition phases and programs. Simulation Based Acquisition is comprised of three principal components. The first is an *advanced systems engineering environment* that uses formal methods and automation to support efficient design synthesis, capture, and assessment, as well as other complex life-cycle activities. The second component is a *refined system acquisition process* that takes advantage of the SBA systems engineering environment capabilities. The third component is a culture that has evolved to a point where *enterprise-wide cooperation* is the rule, and individual technical contributions and innovations are encouraged and managed efficiently.

The objectives of SBA are to:

(1) Reduce the time, resources, and risk associated with the acquisition process
(2) Increase the quality, military utility, and supportability of systems developed and fielded
(3) Enable integrated product and process development from requirements definition and initial concept development through testing, manufacturing, and fielding

Simulation Based Acquisition *is not an incremental step* beyond current system engineering methods and tools. Instead, it represents *a major paradigm shift* toward a comprehensive, integrated environment that addresses the entire system development life cycle and the spectrum of engineering and management domains.

Modeling and simulation can be effectively used on S&T programs to evaluate the affordability of the technologies under study. Simulations can be used to evaluate the producibility of the technology. Models and simulations can be used to assess risk and to project costs.

5.0 REFERENCES

The following technical references and affordability-related web pages were used to prepare this guidebook. They are provided for additional edification and detail on topics of interest.

5.1 Technical References.

a. Quality Function Deployment (QFD)

(1) Anthony, M. and A. Dirik (1995). "Simplified Quality Function Deployment for High-Technology Product Development," Visions, April, pp. 9-12.
(2) Dean, E. B. (1993). "Quality Function Deployment for Large Systems", Transactions of the Fifth Symposium on Quality Function Deployment, Novi, MI, 21-22 June, pp. 165-174.
(3) Gillespie, L. K. et. al. (1990). Quality Function Deployment as a Mechanism for Process Characterization and Control, Allied-Signal Aerospace Co. Kansas City MO, July, DE90-014755, KCP-613-4276.
(4) Guinta, L. R. and N. C. Praizler (1993). The QFD Book, American Management Association, New York, NY, USA.
(5) Reed, B. M., D. A. Jacobs, and E. B. Dean (1994). "Quality Function Deployment: Implementation Considerations for the Engineering Manager," Proceedings of the IEEE International Engineering Management Conference, 17-19 October, Dayton, OH, USA, pp. 2-6.
(6) Schubert, M. A. (1989). "Quality Function Deployment - A Comprehensive Tool for Planning and Development," Proceedings of the IEEE 1989 National Aerospace and Electronics Conference NAECON 1989, Dayton OH, 22-26 May, pp. 1498-1503.

b. Design of Experiments (DOE)

(1) Barker, T. B., “Quality by Experimental Design,” 2nd Edition, Marcel Dekker, Inc, New York, NY, 1994.
(2) Box, G. E. P., W. G. Hunter, and J. S. Hunter, “Statistics for Experiments,” John Wiley & Sons, New York, NY, 1978.
(3) Davies, O L., “The Design and Analysis of Industrial Experiments,” Reprint (corrected version) of 2nd Edition, Hafner Publishing Co., New York, NY, 1978.
(4) Fisher, R. A. and F. Yates, “Statistical Tables for Biological, Agricultural, and Medical Research,” (4th Edition), Edinburgh and London: Oliver & Boyd, Ltd., 1953.
(5) Hicks, C. R., “Fundamental Concepts in the Design of Experiments,” Holt, Rinehart, and Winston, Inc., New York, NY, 1982.
(6) Schmidt, S. R. and R. G. Launsby, “Understanding Industrial Designed Experiments,” Air Academy Press, Colorado Springs, CO, 1989.
(7) Taguchi, G., “Introduction to Quality Engineering,” American Supplier Institute, Inc., Dearborn, MI, 1986.

c. Six-Sigma and Statistical Process Control

(1) Coppola, A., “TQM Toolkit,” Reliability Analysis Center, Rome, NY, 1993.
(2) Grant, E. L. and R. S. Leavenworth, “Statistical Quality Control”, McGraw-Hill, New York, NY, 1989
(3) Harry, Mikel J. and Reigle Stewart, “Six Sigma Mechanical Design Tolerancing,” Motorola University Press, Schaumburg, IL.
(4) Harry, Mikel J. and J. Ronald Lawson, “Six Sigma Producibility Analysis and Process Characterization,” Motorola University Press, Schaumburg, IL.
(5) Hartz, M. and T. Crosier, “A Guide for Implementing Total Quality Management,” Reliability Analysis Center, Rome, NY, 1992.
(6) Lawson, Ron and Bob Stuart, “Measuring Six Sigma and Beyond: Continuous vs Attribute Data,” Motorola University Press, Schaumburg, IL.

d. Cost as an Independent Variable (CAIV)

(1) Conrow, Dr. Edmund H., “Some Potential Benefits of Using CAIV in Defense Programs,” Program Manager Magazine, Nov-Dec 96.
(2) Higgins, Guy, Captain, USN, “CAIV--An Important Principle of Acquisition Reform,” Program Manager Magazine, Jan-Feb 97.
(3) Kausal, B.A, IV, “Controlling Costs--A Historical Perspective,” Program Manager Magazine, Nov-Dec 96.
(4) Land, J Gerald, “Differences in Philosophy - Design to Cost vs Cost As An Independent Variable,” Program Manager Magazine, Mar-Apr 97.
(5) Rush, Dr. Benjamin C., “Cost As An Independent Variable: Concepts and Risks,” Acquisition Review, DSMC, Spring 1997.
(6) Wollover, David R., “Quality Function Deployment as a Tool for Implementing Cost as an Independent Variable”, Acquisition Review, DSMC, Summer 1997.

e. Simulation Based Acquisition (SBA)

(1) Fallin, Dr. Herbert, “SBA Briefing to Industry Steering Group,” 12 August 1997, Office of the Assistant Secretary of the Army (RDA).
(2) Hammond, Marvin H., “The Role of Distributed Simulation in Defense Acquisition,” Institute for Defense Analysis, November 1993.
(3) Portmann, Helmut H., “Study on the Application of Modeling and Simulation to the Acquisition of Major Weapons Systems,” (Draft), The American Defense Preparedness Association, August 20, 1996.
(4) Patenaude, Anne, “Final Report, Study on the Effectiveness of Modeling and Simulation in the Weapon System Acquisition Process,” Science Application International Corporation,

October 1996. Study commissioned by Dr. Patricia Sanders, Deputy Director, Test, Systems Engineering and Evaluation.

(5) "Simulation, Test, and Evaluation Process (STEP) Guidelines," OUSD(A&T), December 4, 1997.

5.2 Policy and Procedures References

(1) Criteria for Assuring a Focus on Affordability in S&T Program Management, Affordability Task Force, Revised December 1997.

(2) Under Secretary of Defense (Acquisition & Technology) Memorandum, August 7, 1996: "Science and Technology (S&T) Affordability Policy."

(3) Director of Defense Research and Engineering Memorandum, Undated, "Science and Technology (S&T) Affordability Task Force."

(4) Deputy Director of Defense Research and Engineering Memorandum, 7 July 1995: "Science & Technology (S&T) Affordability Task Force."

(5) Deputy Director of Defense Research and Engineering Memorandum, 7 July 1995: "Science & Technology (S&T) Affordability Task Force Action Items."

(6) DoD 5000.2-R, "Mandatory Procedures for Major Defense Acquisition Programs (MDAPs) and Major Automated Information System (MAIS) Acquisition Programs," Section 2.5, Affordability.

(7) Defense Science and Technology Strategy, Section V, Management and Oversight of the S&T Program, Guiding Principles for S&T Management, Part 2. Reduce Both Acquisition and Life Cycle Costs.

5.3 DoD Affordability-Related Internet Web Pages

Department of Defense (DoD)

ACQWEB **http://www.acq.osd.mil/**

The Office of the Under Secretary of Defense for Acquisition and Technology (USD(A&T)), providing access to information on unclassified activities, documents, and projects.

Defense Acquisition Deskbook **http://www.deskbook.osd.mil/**

A Department of Defense entry point for acquisition information, a place to receive up-to-date policy and procedure and to receive answers to acquisition questions, and a way to communicate with the acquisition community.

Integrated Product and Process Development
http://www.acq.osd.mil/te/programs/se/ippd/index.htm

Provides information of DoD policies and procedures, training courses available, related publications and speeches concerning the topic of IPPD.

Defense LINK http://www.defenselink.mil/

A Department of Defense World-Wide Web Information Service, providing access to DoD news, events, speeches, and other information.

Defense Research and Engineering (DDR&E) http://www.dtic.mil/ddre/

Provides assistance and advisory services to the Under Secretary of Defense for Acquisition and Technology (USD (A&T)) for DoD scientific and technical matters, basic and applied research, and advanced technology development.

Deputy Under Secretary of Defense (Science and Technology) http://www.dtic/mil/dusdst/

Web site of DUSD(S&T), Dr. Dolores Etter.

Director, Test, Systems Engineering & Evaluation
http://www.acq.osd.mil/te/programs/se/ippd/index.htm

Provides policies and procedures for IPPD, including a handbook and guide for IPPD practices.

Defense Technical Information Web (DTIW) http://www.dtic.mil/dtiw/

A resource for accessing DoD scientific, technical, and acquisition information.

Defense Science and Technology Planning http://www.dtic.mil/dstp/

Provides a single location for 1998, 1997, and 1996 science and technology planning documents and selected related documents of the Department of Defense.

DOD Affordability Programs (Partial Listing)

Miniature Air Launched Decoy http://www.darpa.mil/tto/mald.html

DARPA program to develop a small, low cost, expendable air-launched decoy to enhance the survivability of friendly aircraft and to aid in establishing air superiority by diluting and confusing surface-based and airborne enemy air defense systems.

Composites Affordability Initiative
http://mantech_nt.bmpcoe.org/book/archive/M0881.html

Cooperative effort between industry and (Navy/AF) intended to address the inhibitors, problems, and issues associated with reducing the cost of aircraft constructed with composite materials.

Nanoscale Coatings http://www.onr.navy.mil/onr/newsrel/nr971001.html

Use of these coatings that exhibit an extraordinary combination of hardness, toughness, abrasion-resistance, and adherence on ships and aircraft in order to reduce the cost of fleet maintenance.

Advanced Enclosed Mast/Sensor (AEM/S) System
http://www.spear.navy.mil/ships/dd968/aemspr.htm

Description of ONR-sponsored affordability program to build a composite AEM/S System that is a 93' high, hexagonal structure, 35' in diameter, enclosing existing radars and providing important signature and other operational benefits.

DARPA Programs

Defense Advanced Research Projects Agency (DARPA) **http://www.darpa.mil/**
DARPA manages and directs selected basic and applied research and development projects for DoD, and pursues research and technology where risk and payoff are both very high and where success may provide dramatic advances for traditional military roles and missions.

Affordable Multi-Missile Manufacturing (AM3) **http://www.darpa.mil/tto/am3.html**
A program established to demonstrate advance missile design and manufacturing concepts and manufacturing enterprise systems that reduce the cost of DoD's portfolio of tactical missiles and smart munitions.

Rapid Design Exploration and Optimization
http://www.arpa.mil/DSO/rd/Manufact/Radeo/radeo.html
ATD which is creating a highly flexible and responsive design environment that can be used to evaluate an order of magnitude more design alternatives than is possible today in an attempt to optimize product characteristics (such as performance, manufacturability, assemblability, quality, reliability, and maintainability), and quickly prototype complex products and processes.

Simulation-Based Design (SBD) **http://sbdhost.parl.com/**
This DARPA program is applying virtual prototyping to the acquisition and life cycle support of complex military and commercial systems. It holds the promise of substantially reducing their cost, risk and time to market while resulting in a superior product meeting all customer requirements and expectations.

Military Services

Air Force Manufacturing Technology (ManTech) Program
http://www.ml.wpafb.af.mil/divisions/mlm/mlm.html
Information on Wright Laboratory's manufacturing divisions and programs offices in addition to access to reports and publications.

Army Manufacturing Technology (ManTech) Program
http://ippd.redstone.army.mil/mst_army/mantech_97/
Supports the development and implementation of advanced manufacturing technologies for the production of Army Materiel throughout the product life cycle.

Army Aviation & Missile Command's Manufacturing Technology Division
http://ippd.redstone.army.mil/mt_div/
Executes and manages a program of manufacturing activities for specific weapon systems that insure adequate consideration of factory-floor requirements are incorporated into product designs during the weapon system's development and transition to production.

Best Manufacturing Practices (BMP) Program **http://www.bmpcoe.org**
Seeks to identify the best practices in the areas of design, test, production, facilities, logistics, and management, and to encourage industry and government to share information about these practices.

Joint Strike Fighter (JSF) Program **http://www.jast.mil/**
A joint services team creating the building blocks for affordable, successful development of next generation strike weapon systems.

Navy Affordability Modeling **http://www.onr.navy.mil/sci_tech/industrial/afford.htm**
The objective in modeling affordability is to provide Navy planners and decision makers with: a structure to measure and predict system affordability, select the most affordable concepts and designs, enhance affordability of systems currently being acquired and improve the affordability of operational systems.

Navy Manufacturing Technology (ManTech) Program **http://mantech.bmpcoe.org/**
Through this web site you can access Navy ManTech program information, including the annual Project Books, as well as submit manufacturing issues for consideration during the Program's annual planning process.

Selected Education Sources

Defense Acquisition University (DAU) **http://www.acq.osd.mil/dau/**
DAU was established by Congress in 1990 to consolidate and integrate education and training for more than 110,000 people in the Defense Acquisition Workforce. Consortium member schools provide more than 85 acquisition courses to entry, intermediate, and senior level civilian and uniformed personnel to allow them to attain certification in one or more of the 11 defense acquisition career fields.

James Gregory Associates, Inc. **http://www.JamesGregory.com/FramesIndex.html**
Specializes in managing information technology, offering industry and government training to better manage their information assets, aligning them with their strategic business processes. The site provides information about the Air Force IPPD S&T process and tools available to assist S&T managers in conducting affordablity programs.

National Center for Advanced Technologies (NCAT) **http://www.ncat.com/**
NCAT was founded as a non-profit research and education foundation to provide a bridge between government, industry, and academia, and to encourage cooperative efforts on technology development. The site provides information about affordability conferences and NCAT’s IPPD courses.

APPENDIX A

GLOSSARY OF TERMS

GLOSSARY OF TERMS

A.1 DEFINITIONS (Note: definitions are written from the perspective of S&T affordability)

Acquisition Costs. The costs associated with acquiring a new product. R&D or S&T, although usually attributed to specific product development programs, are part of acquisition costs.

Affordability. (1) The demonstration of *best value* in terms of performance, producibility, life-cycle cost and risk. Affordability efforts are directed at the cost-effective acquisition of high-performance systems and equipment and the cost-effective sustainment of those systems to accomplish a mission. (2) A philosophy of program management and a set of program management objectives and tools to build affordable system are able to be procured when needed and within budget, operated at the desired performance level, and maintained and supported within the life cycle budget allocated. (3) Reduced development, production and ownership cost (Dr. Paul G. Kaminski, former USDA&T).

Collateral Costs. Costs incurred in the use of a product, outside of the direct operating and maintenance costs. May include loss of customers dissatisfied with product, loss of lives due to product failure, or environmental cleanup when product pollutes.

Cost. The expenditure of resources (usually expressed in monetary units) necessary to develop, acquire, or use a product over some defined period of time.

Cost As an Independent Variable (CAIV). A strategy for setting *aggressive*, realistic cost objectives for acquiring defense systems, and managing risks to obtain those objectives. Cost objectives must balance mission needs with projected out-year resources, taking into account existing technology as well as high-confidence maturation of new technologies. Once the system performance and objective cost are decided (on the basis of cost-performance tradeoffs), cost becomes a constraint on the acquisition process.

Defense Science and Technology (S&T). DoD research and development efforts that lead to the development of technology for insertion into military systems. Defense S&T programs are divided into three budget categories -- Basic Research (6.1 account), Applied Research (6.2 account), and Advanced Technology Development (6.3 account).

Design of Experiments (DOE). A statistical approach for identifying and improving those factors that impact product performance.

Discretionary O&S Cost. The O&S costs dictated by laws (FAR), policies (National Priorities), management procedures (Acquisition Reform) and other product-independent factors.

Equivalent Cost. A cost not readily measured in terms of dollars. For example, the inability of a failed program to meet mission performance requirements is an equivalent cost.

Intrinsic Cost. Cost dictated by product characteristics such as technology required, performance, design and process manufacturing.

Life Cycle Costs. Life cycle costs (LCC) are the total costs associated with acquiring (purchasing), operating and supporting, and eventually disposing of a product. LCC includes acquisition costs and operating and support costs. *Affordability is a function of these two basic categories of costs - Acquisition and O&S.* A critical characteristic of life cycle costs, as shown in Figure A-1, is that 90% is determined prior to full scale development, even though at that point, only 10% of the total LCC has been spent.

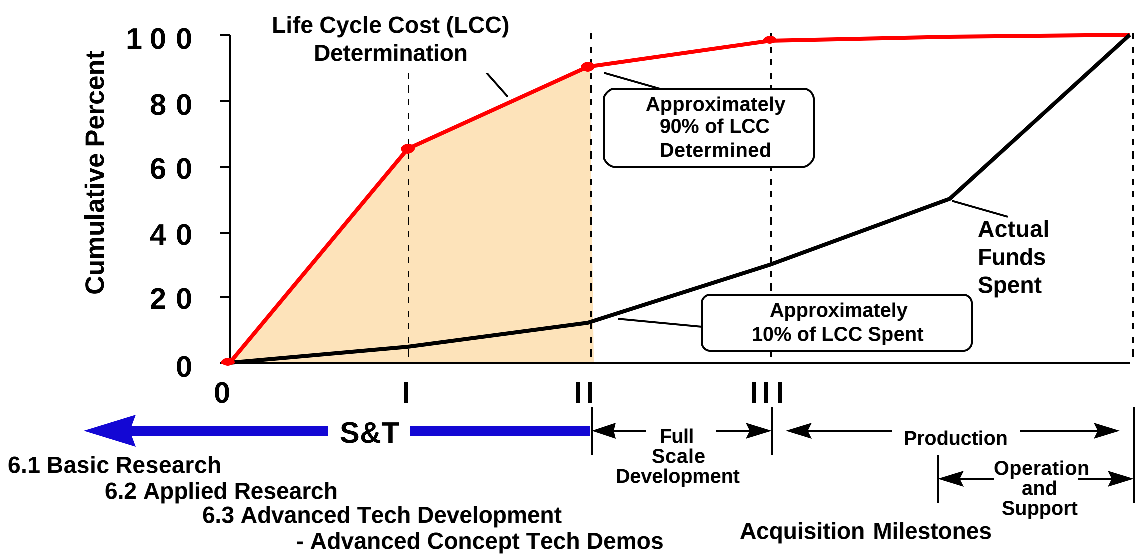

Figure A-1. Life cycle costs are determined very early in a product's life cycle.

Operating and Support (O&S) Costs. Those costs associated with operating and supporting (i.e., using) a product after it is purchased or fielded. These may include collateral, opportunity, and equivalent costs. OS& costs may be intrinsic or discretionary.

Opportunity Cost. The loss of revenue or cost associated with a lost opportunity to invest in a desired manner or to earn income. For example, diverting funds from other programs to allow a failing program to meet its mission performance requirements is an opportunity cost.

Producibility. The inherent ease and economy with which a product may be manufactured. Producibility is a direct function of design (of both the product and the manufacturing processes), the choice of materials, and the technologies incorporated in the design.

Quality Function Deployment (QFD). A tool for translating defined customer requirements into appropriate design requirements at each stage of design and development.

Six-Sigma. The title originally coined and used by Motorola for their initiative to improve their products by reducing variability. Now universally used to describe efforts to control variability so that 99.9% of the products from a manufacturing process will have a parameter value(s) within plus and minus three sigma of the mean value of the parameter. The parameter(s) is the one of most value to the customer and the mean value is usually the specified or desired value of the parameter(s).

Value. Value is a function of the product's characteristics, performance, and the function it is to perform. The customer's perception of the value of the product determines the willingness to buy a product.

A.2 ACRONYMS

Acronym	Definition
ACAT	Acquisition Category
ACTD	Advanced Concept Technology Demonstration
ATD	Advanced Technology Demonstration
ADM	Acquisition Decision Memorandum
CAD	Computer-Aided Design
CAE	Component Acquisition Executive
CAE	Computer-Aided Engineering
CAIV	Cost as an Independent Variable
CAM	Computer-Aided Manufacturing
CTP	Critical Technical Parameters
DAB	Defense Acquisition Board
DAE	Defense Acquisition Executive
DDR&E	Director, Defense Research & Engineering
DoD	Department of Defense
DoDI	Department of Defense Instruction
DOT&E	Director, Operational Test and Evaluation
DTC	Design to Cost
DTSE&E	Director, Test, Systems Engineering and Evaluation
DUSD(S&T)	Deputy Under Secretary of Defense (Science & Technology)
ECP	Engineering Change Proposal
EMD	Engineering Manufacturing Development
ILS	Integrated Logistics Support
IMP	Integrated Master Plan
IMS	Integrated Master Schedule
IPPD	Integrated Product and Process Development
IPS	Integrated Program Summary
IPT	Integrated Product Team
JROC	Joint Requirements Oversight Council

LRIP	Low-Rate Initial Production
MANTECH	Manufacturing Technology
MDA	Milestone Decision Authority
MNS	Mission Need Statement
MOU	Memorandum of Understanding
NDI	Non Developmental Item
OIPT	Overarching Integrated Product Team
ORD	Operational Requirements Document
OSD	Office of the Secretary of Defense
POM	Program Objective Memorandum
PPBS	Planning, Programming, and Budgeting System
PRDA	Program Research and Development Agreement
QFD	Quality Function Deployment
RFI	Request for Information
RFP	Request for Proposals
S&T	Science and Technology
SETA	Systems Engineering and Technical Agent
SOW	Statement of Work
SSEB	Source Selection Evaluation Board
SSP	Source Selection Plan
TEMP	Test and Evaluation Master Plan
TPM	Technical Performance Measures
UAV	Unmanned Air Vehicle
USD(A&T)	Under Secretary of Defense for Acquisition and Technology
WBS	Work Breakdown Structure

APPENDIX B

DETAILED DISCUSSION OF SELECTED AFFORDABILITY MANAGEMENT TOOLS

AFFORDABILITY MANAGEMENT TOOLS

B.1 Introduction. This section provides information on some of the more significant tools available to support managers in meeting affordability goals. These tools are:

- Integrated Product and Process Development (IPPD)
- Integrated Product Teams (IPTs)
- Quality Function Deployment (QFD)
- Design of Experiments (DOE)
- Design for Six-Sigma
- Cost as an Independent Variable (CAIV)

B.2 Integrated Product and Process Development (IPPD)

B.2.1 Introduction. The ultimate goal of DoD acquisition is to provide the warfighters with world-class equipment and systems at an affordable cost and on a schedule that is responsive to the need. Accordingly, William J. Perry, then Secretary of Defense, directed on May 10, 1995, the "immediate implementation" of a management process called Integrated Product and Process Development (IPPD) throughout the acquisition process to the maximum extent practicable.

As a result of the changes made by Secretary Perry, DoD is shifting from an environment of regulation and enforcement to one of incentivized performance. The objective is to be receptive to ideas from the field, thereby obtaining buy-in and lasting change. IPPD is part of the change in the DoD environment.

B.2.2 Background. IPPD has been successfully used by the private sector and by the Services on selected programs to reduce product cost and to field products sooner. It is a management technique that simultaneously integrates all essential acquisition activities through the use of multi-disciplinary teams to optimize the design, manufacturing, business, and supportability processes. IPPD has its roots in integrated design and production practices, concurrent engineering, and total quality management. In the early 1980s, U.S. industry used the concept of integrated design as a way to improve global competitiveness.

Industry's implementation of IPPD expanded concurrent engineering concepts to include all disciplines, not just technical, associated with the design, development, manufacture, distribution, support, and management of products and services. Diverse segments of U.S. industry have successfully implemented this concept to become recognized leaders in IPPD practices, most notably in the auto and electronics industry. Many corporations have institutionalized the IPPD process and associated training programs.

B.2.3 Definition. DoD defines IPPD as, "A management process that integrates all activities from product concept through production/field support, using a multi-functional team, to simultaneously optimize the product and its manufacturing and sustainment processes to meet cost and performance objectives." IPPD evolved from concurrent engineering, and is sometimes called integrated product development (IPD). It is a systems engineering process integrated with sound business practices and common sense decision making. Organizations may need to undergo profound changes in culture and processes to successfully implement IPPD.

IPPD activities focus on the customer and meeting the customer's need. In DoD, the customer is the user. Accurately understanding the various levels of users' needs and establishing realistic requirements early in the acquisition cycle is now more important than ever. Trade-off analyses are made among design, performance, production, support, cost, and operational needs to optimize the system (product or service) over its life cycle. In order to afford sufficient numbers of technologically up-to-date systems, cost is a critical component of DoD system optimization. Cost should not simply be an outcome as has often been the case in the past. Thus, cost should become an independent rather than dependent variable in meeting the user's needs.

B.2.4 Implementation. Although there are common factors in all known successful IPPD implementations, IPPD has no single solution or implementation strategy. Its implementation is product and process dependent. A generic IPPD iterative process is shown in Figure B-1.

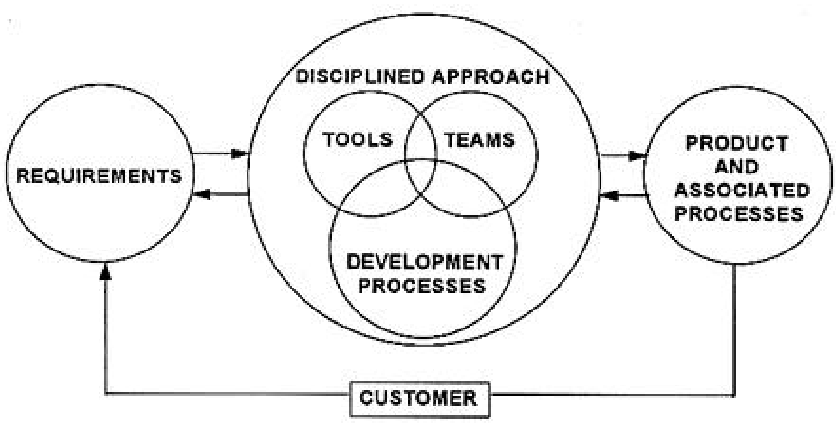

Figure B-1. A Generic IPPD Iterative Process

Resources applied include people, processes, money, tools, and facilities. The IPPD process reorders decision making, brings downstream and global issues to bear earlier and in concert with conceptual and detailed planning, and relies on applying functional expertise in a team-oriented manner on a global-optimization basis. It is necessary to understand early the processes needed to develop, produce, operate and support the product. Equally important are these processes' impacts on product design and development. Basic elements of the iterative process are:

Requirements, a first step in the iterative process above, are generated by the customer in a negotiation among many parties, each with serious and important concerns. Knowing and understanding the customers (command structure, doctrine, tactics, operating environment, etc.) and their needs is essential. Integrating the user's requirements, logistical requirements, and the acquirer's budgetary and scheduling constraints is a fundamental challenge in DoD acquisition.

Disciplined approach includes five general activities: understanding the requirements, outlining the approach, planning the effort, allocating resources, and executing and tracking the plan. Decisions made using this approach should be re-evaluated as a system matures and circumstances (budgetary, threat, technology) change. A disciplined approach provides a framework for utilizing tools, teams, and processes in a structured manner that is responsive to systematic improvement efforts.

- Tools in this IPPD process include documents, information systems, methods, and technologies that can be fit into a generic shared framework that focuses on planning, executing and tracking. Tools help define the product(s) being developed, delivered or acted upon, and relate the elements of work to be accomplished to each other and to the end product. Examples of tools used include integrated master plans, 3-D design tools and their associated databases, cost models linked to process simulations/activity-based costing, metrics, development process control methods, and earned value management.

- Teams are central to the IPPD process. Teams are made up of everyone who has a stake in the outcome or product of the team, including the customer and suppliers. Collectively, team members should represent the know-how needed and have the ability to control the resources necessary for getting the job done. Teams are organized and behave so as to seek the best value solution to a product acquisition.

Development Processes are those activities that lead to both the end product and its associated processes. To ensure efficient use of resources, it is necessary to understand what activities are necessary and how they affect the product and each other. Examples include requirements-analysis, configuration management, and detailed design drawings.

Product and Associated Processes include what is produced and provided to the customer. Customer satisfaction with the product, in terms of mission effectiveness, as well as operating and support aspects and costs, is the ultimate measure of the team's success.

Customer is the user and a team member and also the ultimate authority regarding the product. Any changes to the formal requirements driving the product/process development must come through negotiation with the customer.

The generic IPPD iterative process just described is a systems engineering approach. It differs from the long held view that systems engineering is essentially a partitioning, trade-off, control process that brings the “-ilities” and test functions together. The IPPD process controls the evolution of an integrated and optimally balanced system to satisfy customer needs and to provide data and products required to support acquisition management decisions which, themselves, are part of the IPPD/IPT process. The approach also transforms the stated needs into a balanced set of product and process descriptions. These descriptions are incrementally matured during each acquisition phase and used by DoD and its contractors to plan and implement a solution to the user needs. This process balances cost, system capability, manufacturing processes, test processes, and support processes, as identified in DoD Instruction 5000.2.

The IPPD process is an integrated team effort within DoD and contractor organizations and with each other. DoD crafts the basic acquisition strategy, almost always with industry assistance. Contractors usually play a significant role in development, design, and manufacturing with DoD in a management role. Both participate in each other's major activities through team membership, and the implementation and use of tools and technology.

To implement IPPD effectively, it is important to understand the interrelated tenets inherent in IPPD. These key tenets, outlined by the Secretary of Defense mandate on IPPD and which are consistent with those found in industry, are:

- Customer Focus
- Concurrent Development of Products and Processes
- Early and Continuous Life Cycle Planning
- Maximize Flexibility for Optimization and Use of Commercial Business Approaches
- Encourage Robust Design and Improved Process Capability
- Event-Driven Scheduling
- Multi-disciplinary Teamwork
- Empowerment
- Seamless Management Tools
- Proactive Identification and Management of Risk

Customer Focus. The primary objective of IPPD is to identify and satisfy the customer's needs better, faster, and cheaper. The customer's needs should determine the nature of the product and its associated processes.

Concurrent Development. Processes should be developed concurrently with the products they support. It is critical that during product design and development the processes used to manage, develop, manufacture, verify, test, deploy, operate, support, train people, and eventually dispose of the product be considered. Product and process design and performance should be kept in balance to achieve life-cycle cost and effectiveness objectives. Early integration of design elements can result in lower costs by requiring fewer costly changes late in development.

Life Cycle Planning. Planning for a product and its processes should begin early in the science and technology phase (especially advanced development) and extend throughout every product's life cycle. Early life-cycle planning, which includes customers, functions, and suppliers, lays a solid foundation for the various phases of a product and its processes. Key program activities and events should be defined so that progress toward achievement of cost-effective targets can be tracked, resources can be applied, and the impact of problems, resource constraints and requirements changes can be better understood and managed.

Flexibility. Requests for Proposals (RFPs) and contracts should provide maximum flexibility for employment of IPPD principles and use of contractor processes and commercial specifications, standards, and practices. They should also accommodate changes in requirements and incentivize contractors to challenge requirements and offer alternative solutions that provide cost-effective solutions.

Robust Design and Process Capability. The use of advanced design and manufacturing techniques that promote (1) achieving quality through design for products with little sensitivity to variations in the manufacturing process (robust design), (2) a focus on process capability, and (3) continuous process improvement. Variability reduction tools such as ultra-low variation process control similar to "Six Sigma" and lean/agile manufacturing concepts should be encouraged.

Event-Driven Scheduling. A scheduling framework should be established which relates program events to their associated accomplishments and accomplishment criteria. An event is considered complete only when the accomplishments associated with that event have reached completion as measured by the accomplishment criteria. This event-driven scheduling reduces risk by ensuring that product and process maturity are incrementally demonstrated prior to beginning follow-on activities.

Teamwork. Multi-disciplinary teamwork is essential to the integrated and concurrent development of a product and its processes. The right people at the right place at the right time are required to make timely decisions. Team decisions, as a result of risk assessments, should be based on the combined input of the entire team (technical, cost, manufacturing and support functions and organizations) including customers and suppliers. Each team member needs to understand his or her role and must support the roles of the other members, as well as understand the constraints under which team members operate. All must operate so as to seek global optima and targets.

Empowerment. Decision making should be driven to the lowest possible level commensurate with risk. Resources should be allocated to levels consistent with risk assessment authority, responsibility and the ability of people. The team should be given the authority, responsibility, and resources to manage its product and its risk commensurate with the team's capabilities. The authority of team members needs to be defined and understood by the individual team members. The team should accept responsibility and be held accountable for the results of its efforts. Management practices within the teams and their organizations must be team-oriented rather than structurally-, functionally-, or individually-oriented.

Management Tools. A framework should be established that relates products and processes at all levels to demonstrate dependencies and interrelationships. A management system should be established that relates requirements, planning, resource allocation, execution and program tracking over the product's life cycle. This integrated or dedicated approach helps ensure teams have all available information thereby enhancing team decision making at all levels. Capabilities should be provided to share technical, industrial, and business information throughout the product development and deployment life cycle through the use of acquisition and support shared information systems and software tools (including models) for accessing, exchanging, validating, and viewing information.

Proactive Risk management. Critical cost, schedule and technical parameters related to system characteristics should be identified from risk analyses and user requirements. Technical and business performance measurement plans, with appropriate metrics, should be developed and compared to best-in-class government and industry benchmarks to provide continuing verification of the effectiveness and degree of anticipated and actual achievement of technical and business parameters.

Integrated Product Teams (IPTs) are essential to the IPPD process. See B.3 for a discussion of IPTs.

B.2.5 Benefits. Applying the IPPD management philosophy can result in significant benefits to the customer, DoD, and industry. The primary benefits are reduced cost and schedule while maintaining, often increasing, quality. Essentially, a more balanced tradeoff is achieved among cost, schedule and performance. These gains are realized by the early integration of business, contracting, manufacturing, test, training, and support considerations in the design process, resulting in fewer costly changes made later in the process (e.g., during full rate production or operational test). In a traditional approach, the largest number of changes occur late in development, when change costs are high, resulting in higher program costs. In an IPPD process, the bulk of changes occur early in development, when change costs are low, resulting in lower program costs.

The traditional acquisition approach involved each specialist group completing its work in isolation and then passing results on to the next specialist group. This serial approach has resulted in stovepipe competition for organizational rewards. It establishes walls between organizations with resulting inefficiency and ineffectiveness, including a lack of networking and inter-functional communication.

Use of IPPD and IPTs is the antithesis of the traditional approach. The central notion is that product quality and user satisfaction can best be achieved by the integrated concurrent design of the product and its processes. In IPPD, for example, future process requirements are identified and integrated into the evolving product design early in the design phase. However, IPPD does not stop with a one-time identification of process requirements. As product design matures, continued emphasis is placed on the processes, and their attendant costs, required to manufacture, operate, and support the product. This approach greatly reduces the risk associated with design and development. Product and process maturity are achieved earlier, obviating some of the costly late redesign efforts that characterize traditional developments. Moreover, the up-front trade-offs result in more cost-effective designs. Designs can be optimized for cost effectiveness based not exclusively on acquisition cost, but on overall life cycle cost. Such considerations can be critical, since operations and support costs may far exceed acquisition cost. Successful IPPD implementation can result in:

- Reduced overall time to deliver an operational product. Decisions that were formerly made sequentially are now made concurrently and from an integrated perspective. These decisions are based on a life cycle perspective and should minimize the number and magnitude of changes during manufacturing and eventual operational deployment of the product. This in turn reduces late, expensive, test-fix and test-redesign remanufacture cycles that are prime contributors to schedule extensions and overruns.
- Reduced system (product) cost. Increased emphasis on IPPD at the beginning of the development process impacts the product/process funding profile. Specifically, funding profiles based on historical data may not be appropriate. Some additional funds may be

required in the early phases, but the unit costs as well as total life cycle costs should be reduced. This will be primarily due to reduced design or engineering changes, reduced time to deliver the system, and the use of trade-off analyses to define cost-effective solutions.

- Reduced risk. Up-front team planning and understanding of technologies and product processes permits better understanding of risk and how it impacts cost, schedule, and performance. This understanding can result in methods or processes for reducing or mitigating assumed risks and establishing realistic cost, performance and schedule objectives.
- Improved quality. Teamwork coupled with a desire for continuous improvement results in improved quality of the processes and a quality product for the user.

B.2.6 Barriers. IPPD can provide tremendous leverage in managing product development. However, situations can develop throughout the process that can impede IPPD implementation or its effective use. Like most barriers of this nature, careful planning and vigilance can identify these problems and mitigate them as they arise. Some of the more common barriers are:

- Lack of commitment
- Resistance to cultural change
- Incomplete integration of functional organizations
- Lack of planning
- Insufficient education/training
- Poor communications
- "Not invented here" syndrome
- Contractually imposed specifications or standards requiring IPPD
- IPPD implemented by contractor but not by DoD
- No awards for IPPD approach
- Promises exceed capability
- Poor incentives/award fees criteria
- Over-extended reviews

A description of these common barriers follows:

Lack of Commitment. The first principle of successful IPPD implementation is to obtain unequivocal top management commitment. Without total top management commitment many employees may view IPPD as just another fad. Recommendation: Obtain a written commitment from senior management to the principles of IPPD and its application to the program/product/service at issue before embarking on this effort.

Resistance to Cultural Change. Given current approaches, cultural change is required for the IPPD process to work. Because of the hierarchical structure of the military services, adaptation to the IPPD method of doing business may be difficult due to the changing roles of the different staffs. This perception can become more pronounced as differences in rank increase. It is essential that an atmosphere with freedom to express ideas without repercussion from those conflicting views is created. Do not underestimate the forces of resistance to change. Spend what may seem like an inordinate effort on cultural change management. To the maximum extent possible, use a rewards system to recognize and encourage the desired change.

Incomplete Integration of Functional Organizations. Functional organizations are responsible for technology development, personnel development, process improvement, and administrative functions. These activities cannot be adequately performed if the functional organization and its people are treated as outsiders to the work to be accomplished. For example, process improvement can only occur when teams understand and use the processes developed by the functional organizations. With the implementation of IPPD, the role of the functional organization changes from controlling the work of the program to the care and development of the resources available to the team. These include people, information systems, libraries, models, education and training, public and financial recognition, and often operational processes and capital equipment.

Lack of Planning. Planning can be rushed and incomplete as teams quickly form to start an effort already behind schedule. Up-front planning that includes all functions, customers, and suppliers must be accomplished at the start of any team activity. This allows the program activities and work to be defined and the early identification and management of risk. The integrated master plan must be consistent with the project/organization objectives and it must be constantly reevaluated and modified to meet current team needs and capabilities. Resist the temptation to take short cuts - it will cost more later.

Insufficient Education/Training. Education/training has often been overlooked in the process. Sometimes it is assumed that members have received the required training and, therefore, do not require additional education/training. Include IPPD education/training as an integral part of the comprehensive up-front planning. To optimize the effect of training, it should be done immediately before the particular skill is required.

Poor Communications. There is often a lack of communication across programs/organizations in areas of problem solving, lessons learned, and good practices. A formalized, documented process for exchanging information related to IPPD implementation should be created and used.

"Not Invented Here" Syndrome. There is a natural tendency when things are not going well for a team to focus on its immediate problems to the exclusion of other organizations and their needs. A "Not Invented Here" philosophy can develop, causing teams to exclude ideas/inputs from their internal and external customers and co-workers. The key concept that must be stressed is the idea of teamwork—all individuals working together for a common goal. Publicly acknowledge when good ideas are brought in from outside the team.

Contractually Imposed Specifications or Standards Requiring IPPD. To create the appropriate incentive, it is best practice to include the requirement for IPPD as a contractual item. However, it should not be dictated how IPPD will be implemented because contractors will be hesitant to deviate from contractually-imposed standards for fear of being found non-responsive. The contractor selected should already have established an IPPD culture and should not need steps for implementation dictated by DoD. If "how-to" details are presently imposed in existing contracts, seek to remove them, if feasible.

IPPD Implemented by Contractor But Not DoD. Problems may arise when DoD expects contractors to use IPPD approaches but does not participate in IPPD tools, teams, or processes. DoD must suppress the tendency to monitor progress along functional lines, to conduct design reviews function by function, and to mandate accounting methods that inhibit IPPD.

No Awards for IPPD Approach. It will not take long for contractors to pick up on the fact that DoD may ask for new and innovative IPPD approaches in the RFP, but still awards contracts based on lowest cost and traditional approaches. If the IPPD approach is to work, DoD's commitment must be real.

Promises Exceed Capability. The possibility of contractors promising more than they can deliver has always been a problem for Source Selection Evaluation Boards (SSEBs). This will be an even greater concern in an IPPD environment because, in the spirit of teamwork, a tendency may develop to make oversight less independent. A related trap is if contractors parrot back the IPPD requirements without making the internal cultural changes needed to operate using IPPD techniques. It is important that the SSEB become familiar with successful IPPD techniques/methods and what can realistically be done, perform a thorough technical evaluation of each proposal, and look closely at contractor past performance in IPPD implementation.

Poor Incentive/Award Fee Criteria. Under the IPPD philosophy, the driving force behind incentive/award fees should be successful product/process development. Concurrent product and process development, full life cycle design considerations, and continuous improvements should be the focuses. Unfortunately, some contract incentive criteria can disincentivize contractors from using IPPD. For example, incentivizing only low development cost can cause the contractor to omit needed design analysis, testing, and alternative examination. Incentivizing meeting scheduled milestone events, such as design reviews, causes contractors to meet those dates whether they are ready or not. Better contract incentives can be based on effectiveness of the contractor's IPPD methods and measures of contractor performance in meeting or exceeding contractual requirements. Beware of including criteria that may preclude optimization of the product.

Over-Extended Reviews. When all members of a multi-functional team are encouraged to participate in a design, many questions and issues will be brought up that result in prolonged discussions. A structured agenda for meetings and reviews should allow for the discussion of issues but not allow the discussion to be dominated by any one specific point. Time limits, however, should only be stressed by the meeting facilitator or chairperson when the discussion becomes repetitive, or a consensus cannot be reached.

B.3 Integrated Product Teams (IPTs)

B.3.1 Introduction. Integrated Product Teams are cross-functional teams that are formed for the specific purpose of delivering a product for an external or internal customer. IPT members should have complementary skills and be committed to a common purpose, performance objectives, and approach for which they hold themselves mutually accountable. IPTs are the means through which IPPD is implemented. Members of an integrated product team represent technical, manufacturing, business, and support functions and organizations that are critical to developing, procuring and supporting the product. Having these functions represented concurrently permits teams to consider more and broader alternatives quickly, and in a broader context, enables faster and better decisions.

Once on a team, the role of an IPT member changes from that of a member of a particular functional organization, who focuses on a given discipline, to that of a team member, who focuses on a product and its associated processes. Each individual should offer his/her expertise to the team as well as understand and respect the expertise available from other members of the team. Team chartering is an excellent way of the team understanding roles and responsibilities of both the team and team members. Team members work together to achieve the team's objectives. A critical element of successful IPTs is effective communications within and between IPTs.

B.3.2 Formational Elements. Critical elements in the formation of a successful IPT are:

1. All functional disciplines influencing the product throughout its lifetime should be represented on the team;
2. Clear understanding of the team's goals, responsibilities, and authority should be established among the business unit manager, program and functional managers, as well as the IPT; and
3. Identification of resource requirements such as staffing, funding, and facilities.

The preceding elements can be defined in a team charter that provides guidance.

B.4 Quality Function Deployment (QFD)

B.4.1 Introduction. Quantitative S&T development goals should be derived using the same process used to derive product requirements for specific programs. This process consists of performing a needs analysis and uses tools such as Quality Function Deployment (QFD). QFD is a tool for translating defined customer requirements into appropriate design requirements at each stage of design and development. The method uses a matrix known as the House of Quality, as depicted in Figure B-2.

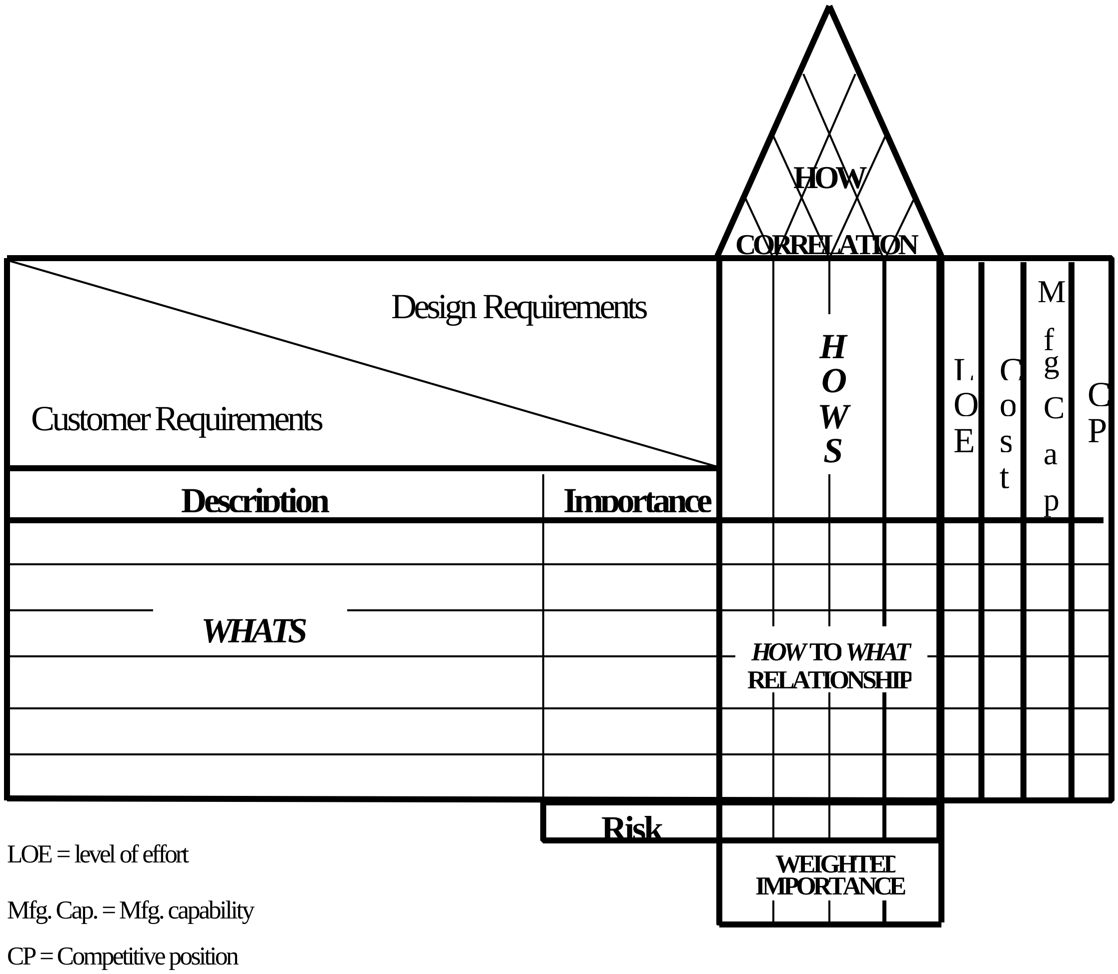

Figure B-2. QFD House of Quality

The following are definitions of the terms used in the House of Quality.

Whats	The product characteristics, functions, or levels of performance wanted by the customer. These are the customer needs or requirements. The *Whats* are sometimes divided into Primary, Secondary, and Tertiary requirements. Examples of each for a fighter aircraft are, respectively, Operating Characteristics, Sorties, and 4 Sorties per Day.
Hows	The ways in which the *Whats* can possibly be met. Also called design requirements. A *How* for the fighter sortie requirement might be a product availability of 0.92
Importance	The value or importance placed by the customer on each *What*. Typically stated as Greatest, Average, or Least.

Hows to *Whats* Relationships	The relative strength of the relationship between a *What* (a requirement) and a specific How. Typically stated as Very Strong, Strong, or Weak or a corresponding numerical value.
Weighted Importance	The importance of each *How* based on either its *How* to *What* relationship value and number of tertiary *Whats* (absolute weighting) or the relationship value, risk, and number of tertiary *Whats* (relative).

Weighted Importance is calculated as follows:

$$\text{Relative weight} = \sum_{i=1}^{N} (\text{Relationship value x importance factor})_i$$

Rank Ordered

$$\text{Absolute weight} = \sum_{i=1}^{N} (\text{Relationship values})_i$$

Rank Ordered

How Correlation - The strength of the technical interrelationships between the *Hows*. Typically stated as Very Strong, Strong, or Weak. Often, positive and negative relationships are indicated using separate symbols.

Risk - The degree of technical and cost risk associated with each *How*. Typically stated as Greatest, Average, or Least.

N - The total number of requirements (Whats).

B.4.2 Implementation Steps. Briefly, the following steps are used in the QFD approach (see example, Figure B-3).

1. Enter the *Whats* already determined. If necessary, further define the *Whats* as Primary, Secondary, and Tertiary requirements.
2. Determine the *Hows*, the design requirements, based on technical experience and knowledge.
3. Develop *What-How* relationships, assigning a numerical value to each (for example, a Very Strong relationship might be assigned a 5, a Strong relationship a 3, and a Weak relationship a 1). Determining relationships is based on experience and technical knowledge. To provide an easily understood graphical display, symbols, as shown in Figure B-3, are used.
4. Define and assign customer importance factor for each of the lowest level (primary, secondary, or tertiary) requirements and the degree of technical and cost risk associated with each *How*. Assign numerical values to the factors and degrees of risk (e.g., Greatest = 5, Average =3, Least =1).

Customer Requirements				Design Requirements		
Primary	**Secondary**	**Tertiary**	**Importance**	DR1	DR2	DR3
OperatIng CharacteIstIcs	A	A-1	○	◉	—	△
		A-2	△	○	◉	—
		A-3	◉	◉	—	○
		A-4	○	△	○	△
	B	B-1	○	△	○	◉
		B-2	△	—	◉	—
		B-3	◉	○	—	◉
	C	C-1	○	—	◉	—
		C-2	△	◉	—	△
	D	D-1	○	○	—	◉
		D-2	△	—	◉	—
		D-3	△	—	△	◉
		D-4	◉	◉	—	—
		D-5	○	—	◉	△
	E	E-1	△	◉	○	—
		E-2	○	○	—	◉
			Risk	△	◉	○
		Weights	Relative	1	3	2
			Absolute	1	2	3

Symbol	Relationships	Importance/Risk
◉	Very Strong = 5	Greatest = 5
○	Strong = 3	Average = 3
△	Weak = 1	Least = 1
—	None	N/A

Figure B-3. Example Excerpt of House of Quality.

5. Develop relationships among the *Hows* (not shown in Figure B-3). Use the same definitions for the strength of the relationship and the corresponding numerical value that were used for the *What-How* relationships. Knowing the relationship among *Hows* will be important during trades.
6. Calculate the relative and absolute weights for the *Hows.* For each *How* (DR1, DR2, and DR3), sum the relationship values in that column. The results are 39, 35, and 32, respectively. Ranked ordered, the *Hows* are given absolute weights of 1, 2, and 3. Now multiply the relationship values in each column by the corresponding importance and add the products yielding the following sums: 117, 67, and 100, respectively. Rank ordered, the relative weights are 1, 3, and 2, respectively, for DR1, DR2, and DR3.
7. Multiply the relative weights by the Risk factors of the *Hows.* The products of this multiplication indicate the attention merited by each *How*. DR2 rates the most attention, DR3 the next most, and DR1 the least.

The right-hand side of the complete House of Quality (reference Figure B-2) is used to project the relative level of effort, cost, required manufacturing capability, and the supplier's competitive position regarding each *What*. Projections are usually stated as Greatest, Average, and Least. By using successive QFD "Houses of Quality", with the *Hows* from one used as the *Whats* of the next, increasingly more detailed (lower level) requirements can be derived.

B.5 Design of Experiments (DOE)

B.5.1 Introduction. Design of Experiments (DOE) is a statistical approach to identify and improve factors that impact product performance. It consists of seven steps:

- Select the factors to be tested and parameters to be measured
- Determine the factor values to be used as test settings
- Set up the test array
- Run the tests
- Analyze the results
- Calculate optimum values for the factors
- Run confirmation tests

DOE is often used in production to determine the optimum settings for production processes. In S&T development, it can be used to optimize performance parameters and to select optimum processes for new products.

B.5.2 Selecting Factors and Parameters. The test factors selected are those which are most likely to impact a product parameter that must be controlled. For example, the users of a wave solder process may wish to control(in this case, minimize) the number of solder defects in printed wiring boards going through the process. To determine how best to do this, they must identify the factors most likely to affect the number of defects. This is best done by a team of people familiar with the process. Possible factors of interest might be solder temperature, wave height, and whether or not flux is used. Since each additional factor increases the cost of the experiment, only the factors reasonably likely to be significant are selected. The parameter to be measured must also be defined. In this case, it could be the average number of defects per board, or the percent of boards coming out of the process that contain a solder defect. (In DOE supporting S&T development, the factors could be different joining processes, such as soldering, welding, and wire wrapping, and the output parameter could be cost per acceptable board.)

B.5.3 Determine Factor Values. The experiment will consist of a series of tests, during which each factor must take at least two different values. It is possible to use more than two values (e.g., test at five different temperatures), but each additional value tested will significantly lengthen the experiment and add complexity to the analysis. The two values selected must be far enough apart so that the difference in their impacts can be observed, but close enough so that the difference is approximately linear with the change in value.

Once the values are selected, they are coded. One could be called "high" and the other "low" (even if the "low" value is greater than the "high" value), or one value could be labeled "plus" and the other "minus." Other labels are also used. The label is an arbitrary designation used to organize the data for analysis. For the wave solder process, test factors could be assigned values as shown in Table B-1.

Table B-1: Test Factors Value Settings

Factor	"plus" setting	"minus" setting
(A) Temperature	400 degrees	380 degrees
(B) Wave height	12 mm	10mm
(C) Flux	Present	Absent

B.5.4 Setting Up the Test Array The test array is simply a matrix showing what combinations of settings will be used in the different iterations of the test. One type of test array is the orthogonal array which permits the easy separation of the effects of each factor. A full Factorial Orthogonal Array will require the testing of every possible combination of high and low values for each factor. This is represented by the three columns of Table B-2 labeled "Tested Factors".

Table B-2: Full Factorial Orthogonal Array

	Tested Factors			Inferred Factors				
Test	**A**	**B**	**C**	**AB**	**AC**	**BC**	**ABC**	**Results**
1	+	+	+	+	+	+	+	
2	-	+	+	-	-	+	-	
3	+	-	+	-	+	-	-	
4	-	-	+	+	-	-	+	
5	+	+	-	+	-	-	-	
6	-	+	-	-	+	-	+	
7	+	-	-	-	-	+	+	
8	-	-	-	+	+	+	-	

The columns labeled "Inferred Factors" are not test settings, but represent the effects of interactions between the tested factors, which can be calculated from the test results. The number of tests required by a full factorial test array is:

No. of tests = 2^n , where n = number of factors, each having two values assigned.

A Full Factorial Orthogonal Array for two factors in our example, say temperature and wave height, is shown in Table B-3.

Table B-3: Full Factorial Orthogonal Array for Two Factors.

Test	TEST FACTORS			Results
	A	B	AB	
1	+	+	+	
2	-	+	-	
3	+	-	-	
4	-	-	+	

When there is little possibility of interaction between the factors, a much more economical test may be run by using the columns for the interactions to determine test settings for additional factors. This is called a "saturated" or fractional orthogonal array[1], and Table B-3 could be used to create a saturated array for seven different factors. For the three factors to be tested in the wave solder process experiment, a saturated array is given by Table B-4. This table is derived from the Full Factorial Orthogonal Array for two factors in Table B-3, by substituting the third factor (C) for the column ordinarily held by the interaction (AB). The "+, -" matrix pattern defining the factor combinations for the four runs was developed using Yates' algorithm.

Table B-4: Saturated Array

Test	TEST FACTORS			Results
	A	B	C	
1	+	+	+	
2	-	+	-	
3	+	-	-	
4	-	-	+	

B.5.5 Running the Test Using Table B-4 as a guide, we would run one test with Factor A (Temperature) at its "plus" setting of 400 degrees, factor B (Wave height) at its "plus" setting of 12 mm and Factor C (Flux) at its "plus" setting (Flux present). Another test would be run with Factor A at its "minus" setting, B at its "plus" setting and C at its "minus" setting. Another test would have Factor A at its "plus" setting and the other two factors at "minus." A fourth test would be run with Factors A and B at "minus" settings and C at its "plus" setting. These tests can be run in any order and each can be repeated as often as felt necessary. For each test, the defect rate would be recorded. If a test is run more than once, the average value of the results is determined.

B.5.6 Analyzing the Results. The measured result of each test shows the effect of the particular values chosen for the test settings. The effect of combinations of settings not tested (i.e., those omitted

---

[1]Fractional factorial designs limit the overall analysis capability. In this case, only the effects of the main factors and some first order interactions can be studied. Fractional factorial design strategies are commonplace and, in fact, form the basis for the majority of Taguchi arrays.

when using a saturated array) and of settings between the “plus” and “minus” values can be determined using linear regression techniques. The average result (test outcome) when a factor is set to its “plus” value is computed from all the tests run with that factor at its “plus” value. From this is subtracted the average result when the factor was set to its “minus” value. The result of this subtraction, called Delta (Δ), is the average difference in the value of the test outcome as the factor varies from “minus’ to “plus.” Assuming a linear relationship, this result can be used to predict the result of setting the factor at any value between “plus” or “minus.” This is illustrated in Table B-5, where some assumed results have been entered, and the regression equations derived.

B.5.7 Calculating Optimal Settings. Since the test results in the example are defect rates, and the lowest defect rate is the desired output, the factors would be set to the value between “plus” and “minus” that result in the smallest value for y. Factor C, the presence or absence of flux, can take on only the values “plus” (present) and “minus” (absent). The other factors can take on any value between “plus” and “minus” representing settings between the high and low values selected for the test. From the equation derived in Table B-5, the optimal settings would be “plus” for Factors A and B and “minus” for Factor C. The expected defect rate at these settings would be 0.1 (y = 1.0 - 0.5 - 0.3 - 0.1 = 0.1). Note that this result is lower than any shown in Table B-5.

Table B-5: Analysis of Test

	TEST FACTORS			
Test	**A**	**B**	**C**	**Results**
1	+	+	+	0.3
2	-	+	-	1.1
3	+	-	-	0.7
4	-	-	+	1.9
Avg.+	$\frac{0.3 + 0.7}{2}$	$\frac{0.3 + 1.1}{2}$	$\frac{0.3 + 1.9}{2}$	$\bar{y} = \frac{0.3 + 1.1 + 0.7 + 1.9}{4}$
Avg. -	$\frac{1.1 + 1.9}{2}$	$\frac{0.7 + 1.9}{2}$	$\frac{1.1 + 0.7}{2}$	$\bar{y} = 1.0$
Δ	-1.0	-0.6	+0.2	NA
$y = \bar{y} + \frac{\Delta A}{2} A + \frac{\Delta B}{2} B + \frac{\Delta C}{2} C$ y = 1.0 - 0.5A - 0.3B + 0.1C				

B.5.8 Run Confirmation Test(s). There is always a danger that the test results reflect the influence of an unknown factor present during the tests. For this reason, it is always good practice to run a confirmation test at the optimized setting to verify that the expected results are indeed achieved. This is especially important when a saturated array is used under the assumption that interactions between the factors are not significant. If the assumption is wrong, the verification test should not give the expected results, and the analyst will know that more work needs to be done.

B.6 Design for Six Sigma.

B.6.1 Introduction. "Six Sigma" is the title used by Motorola for their initiative to improve their products by reducing variability. The impact of variation in a product can be determined by comparing the distribution of the parameter of interest with the specified limits for that parameter. One measure of variation is the population standard deviation (sigma), which is estimated from samples using equation B-1.

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}{n-1}} \qquad \text{(Equation B-1)}$$

where: σ = population standard deviation $\quad x_i$ = value of sample (i)

$\bar{x}$ = mean of sample values $\quad n$ = number of samples

Using the standard deviation, one can determine the proportion of the product for which the measured parameter will be between the upper and lower specified limits, and thus is acceptable. For example, if a parameter is distributed normally, 66.3% of the product will have a parameter value within plus and minus one sigma of the mean value of the parameter, 95.5% between plus and minus two sigma, and 99.7% between plus and minus three sigmas. Figure B-4 illustrates the included percentages for varying +/- values of sigma.

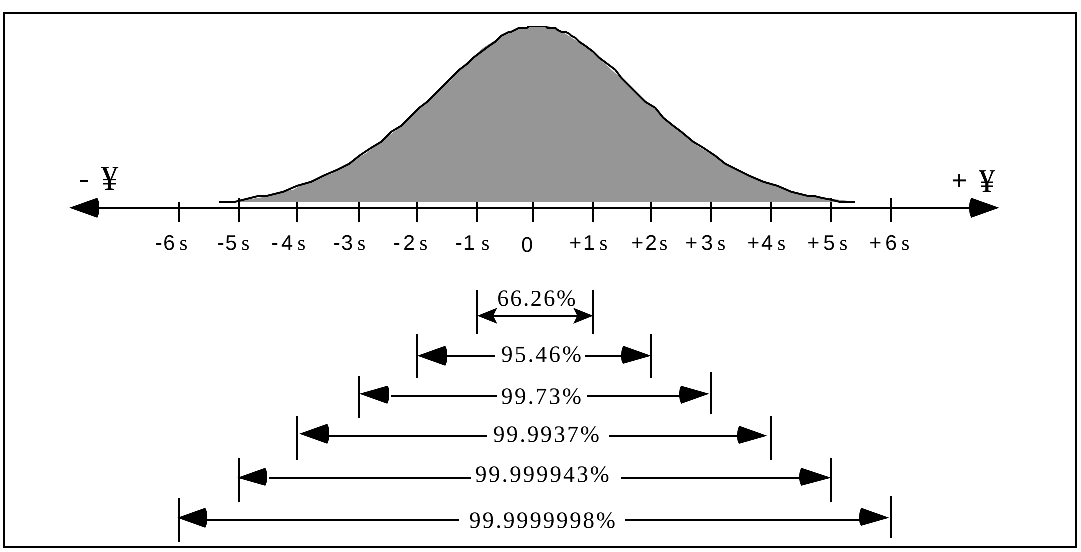

Figure B-4. Percent of population included in +/- sigma ranges.

B.6.2 Process Capability. Comparing the specified limits to the actual variation yields a measure of robustness. One of these measures is Process Capability, which is calculated using Equation B-2. A Process Capability of 1.0 means that 99.7% of the product will be "in-spec." Anything lower is generally considered bad, and quality oriented companies aim at higher values.

$$Cp = \frac{USL - LSL}{6\sigma} \qquad \text{(Equation. B-2)}$$

where: USL = Upper specification limit
LSL = Lower specification limit
σ = Standard deviation

One shortcoming of the Process Capability measure is that it presumes that the mean of the process is the target value for the parameter of interest, as illustrated in Figure B-5.

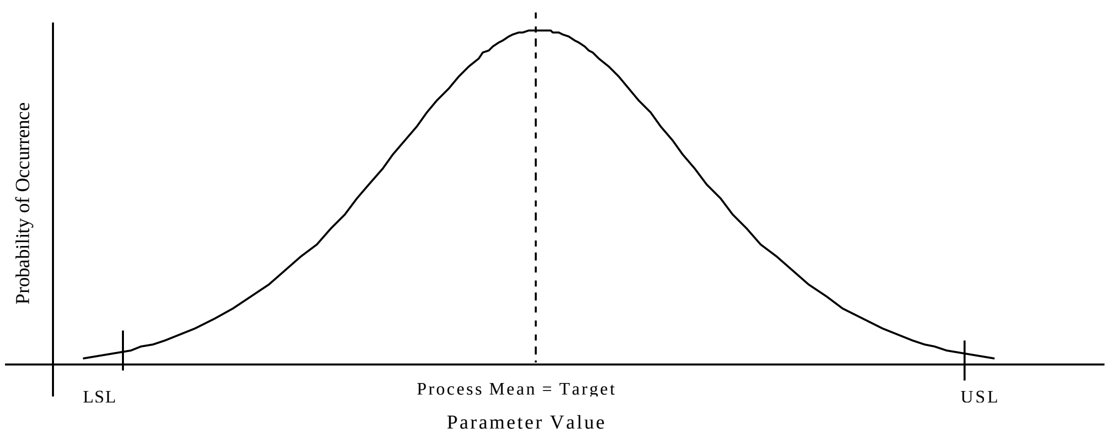

Figure B-5. Process Capability: A Measure of Process Capability with Process Mean Equal to Target Value.

However, "real world" distributions are more likely to resemble Figure B-6, where the process mean value is displaced from the target. For this reason, another measure of process capability called Process Performance, Equation B-3, is often preferred.

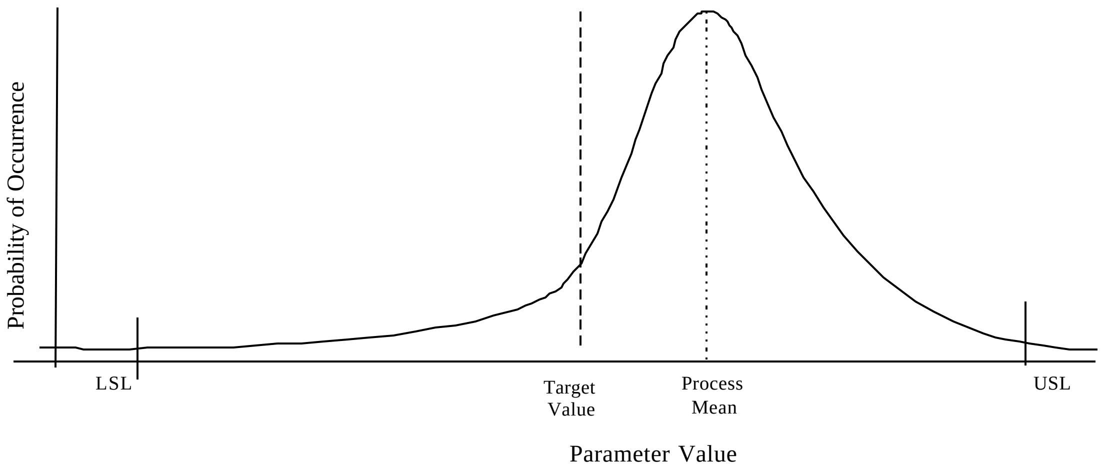

Figure B-6. Process Performance: Measure of Process Capability with Process Mean Shifted from Target.

$$C_{pk} = \frac{\{\text{Min (USL - } m\text{); (} m \text{ - LSL)}\}}{3\,s} \qquad \text{(Equation B-3)}$$

where:

Min{(USL - μ); (μ - LSL)}	=	Smaller of the two values expressed in units of σ
USL, LSL, σ	=	As for equation B-2
μ	=	Process mean

B.6.3 Process Goals. The goal of the "Six Sigma" program formulated by Motorola is for such low variability in the process that a variability of six sigmas in the value of the parameter of interest will fit between the specification limits (i.e., a Process Capability of 2.0). Presuming the mean of the process is 1.5 sigmas off target (i.e., a Process Performance of 1.5), this level of variability translates to 3.4 items per million out of specified limits. By way of comparison, the average business process is a "four sigma" process, which translates to 6,200 items per million "out of spec." Achieving a "six sigma" process requires the control of critical process parameters, which can be identified by the statistical design of experiments, the previous topic.

The need for high levels of process capability can be illustrated by the following example:
The probability of an assembly of n parts having no defects is the part yield raised to the nth power. A "three sigma" process with mean on target produces 99.73% good product. Thus, an assembly of "three sigma" parts would have a probability of no defects (i.e., no parts "out of spec") of .9973 raised to the nth power. For an assembly of ten parts, this is .9733, which may be acceptable. For an assembly of 100 parts, the probability of being defect free is .7631, which is rarely acceptable. For an assembly of 1000 parts, the probability of being defect free is only .06696. Thus, any sizable aggregate of parts cannot be economically produced unless the part variation is controlled to very low levels.

B.6.4 S&T Influence on Six Sigma Production. The achievement of six sigma processes depends on the processes being inherently capable of producing uniform product. Hence, its achievement depends on the selection of the production process. This selection should be done as part of IPPD during S&T development. S&T should include the selection of the optimum processes, which may require some DOE testing or benchmarking of possibly useful processes. Transition to production should not occur before the processes suitable for producing a product are identified and the product is designed to be produced by a sufficiently capable process.

B.7 Cost as an Independent Variable

B.7.1 Introduction. DoD has adopted a new acquisition strategy to meet the future needs of our forces with highly capable systems at affordable costs and possibly shorter schedules. This strategy entails setting *aggressive,* realistic cost objectives for acquiring defense systems, and managing risks to obtain those objectives. Cost objectives must balance mission needs with projected out-year resources, taking into account existing technology as well as high-confidence maturation of new technologies. This concept has become known as “cost as an independent variable” (CAIV), meaning that, once the system performance and objective cost are decided (on the basis of cost-performance tradeoffs), the acquisition process will make cost more of a constraint, and less of a variable, while nonetheless obtaining the needed military capability of the system.

B.7.2 Achieving the CAIV Objectives. A key tenet of the CAIV approach is a far stronger *user* role in the process through participation in setting and adjusting program goals throughout the program, particularly in the cost performance tradeoff process. Working within that context, a process toward achieving the objectives of cost as an independent variable, will include:

- Setting realistic but aggressive cost objectives early in each acquisition program
- Managing risks to achieve cost, schedule and performance objectives
- Devising appropriate metrics for tracking progress in setting and achieving cost objectives
- Motivating government and industry managers to achieve program objectives
- Putting in place for fielded systems additional incentives to reduce operating and support costs.

Several current and past programs, including the Joint Air Strike Technology System (JAST) and the New Attack Submarine, have employed CAIV principles. However, until very recently, goal-setting processes have been largely driven by available technology and generally have not emphasized cost-performance tradeoffs in setting program goals. Furthermore, goals have been set on the basis of near-term budgetary needs--a reality--but not always in balance with life-cycle cost mitigation. By better connecting the user, supporter and developer, the proposed CAIV approach facilitates the process of making tradeoffs among performance, schedule, and costs. Establishing tradeoffs empowers the user to make choices that provide the best performance for the money for each system, thereby helping to ensure maximum benefit from all systems across the force within the resources available.

The best time to reduce life-cycle costs is early in the acquisition process, and cost performance tradeoff analyses must be conducted before an acquisition approach is finalized. However, because external parameters change and program realities evolve, cost-performance tradeoffs must occur throughout the acquisition process. Life-cycle cost objectives should be incorporated in program requirements documents, RFPs, contract provisions, and the source selection process.

Maximizing Program Managers' and contractors' flexibility to make cost/performance tradeoffs without unnecessary higher-level permission is essential to achieving cost objectives. Therefore, the number of threshold items in requirements documents and the Acquisition Program Baselines should be strictly limited and the threshold values should represent true minimums, and requirements should be stated in terms of capabilities, vice technical solutions and specifications. RFPs should include a strict minimum number of critical performance criteria that will allow industry maximum flexibility to meet overall program objectives. Stating requirements in terms of overall military capability needed rather than as detailed design specifications is crucial in providing the necessary trade space and flexibility to implement CAIV successfully.

A major topic upon approval of a Mission Need Statement should be the approach and inputs used to set and refine cost objectives. At each milestone review, cost objectives and progress in achieving them should be assessed. There must be flexibility for adjustments and/or refinement in cost objectives. To assist in establishing program cost objectives and to facilitate cost-performance tradeoffs, the Overarching IPT (OIPT) for each Major Defense Acquisition Program will establish a Cost-Performance Integrated Product Team (CP-IPT). It is critical that the user community have representation on the CP-IPT. Industry representation, at the appropriate time, is also expected.

B.7.2.1 Aggressive Cost Objectives. This means costs objectives that are the "DoD-equivalent" of sound commercial business practices. They should be much lower than would be projected for a system using past ways of doing business in DoD. Reducing life-cycle costs (see Figure B-7) means focusing early on setting and managing to the production cost objective and assessing the impact of basic system parameters and early design decisions on O&S costs. Achieving aggressive cost objectives for the production and operating phases of a system's life may, in fact, occasionally require greater up-front investment during Program Definition and Risk Reduction, and Engineering and Manufacturing Development (EMD) phases. Although lower up-front costs usually indicate simpler designs, and therefore correspondingly lower support costs, there may be cases where certain elements of early program costs may be higher than historical experience because of increased emphasis on product maturity exiting EMD and up-front investments to reduce O&S costs.

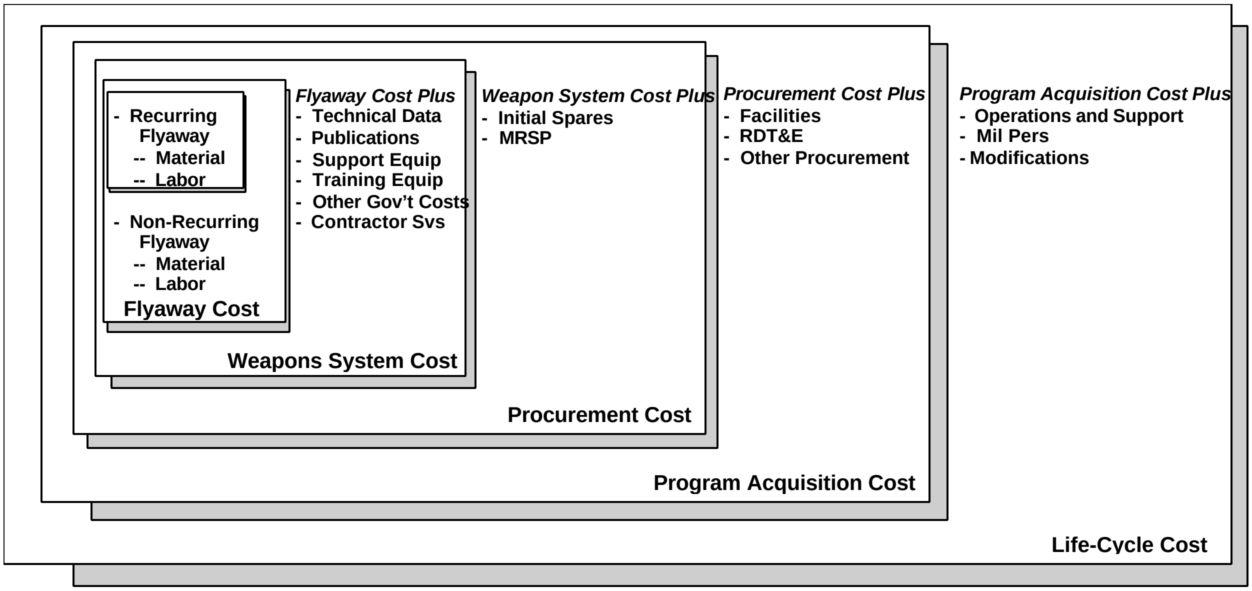

Figure B-7. Definition of Life-Cycle Costs

Life cycle cost objectives (R&D, production, and O&S costs) should reflect consideration of: available near-term and out-year resources; recent unit costs of comparable or fielded systems; parametric estimates; mission effectiveness analysis and trades; technology trends; and use of innovative manufacturing techniques and commercial business practices. Early cost objectives should be challenging but realistic and should be defined as ranges. Aggressive cost objectives will typically entail risks; however, process maturity, aggressive management (under a more failure-tolerant philosophy), and other initiatives should result in lower overall risk.

Production cost objectives should be expressed in terms of some reasonably stable measure, such as an early fixed production quantity (e.g., the first production lot), to eliminate variations due to future changes in the quantities planned or actually produced. (For some programs, it may be appropriate to specify the objective in terms of "first production unit cost.")

Both commercial and defense industries are adopting new design, manufacturing and management processes that offer the potential to reduce development and production times and costs substantially over previous processes. We are stressing increased reliance on commercial business and technical practices and benchmarking commercial processes to define equivalent cost-saving processes for military systems. If given the right incentives and room to make design tradeoffs, industry management and engineers working in IPTs can institute process improvements and system designs that produce products with inherently lower production and operating and support costs and which might be fielded sooner.

B.7.2.2 Managing Risk. Risks in achieving both performance and aggressive costs goals must be clearly recognized and actively managed through continuing iteration of cost/performance/ schedule/risk tradeoffs, identifying key performance and manufacturing process uncertainties and demonstrating solutions prior to production. Risk reduction through use of mature processes should be a significant factor in source selection, since the production cost objective can only be achieved by demonstrating and bringing key manufacturing processes to maturity. Whereas DoD has traditionally managed performance risk, there must be an equal emphasis on managing toward cost and supportability goals. Cost and risk management involves constructing a plan and schedule of events and demonstrations to verify solutions to cost/risk problems. It further involves unit procurement and O&S cost tracking models that will update cost predictions based on observed events and metrics as program progress. Table B-6 contains examples of illustrative cost factors and indicators that can contribute to assessing cost objective achievement.

Table B-6: Illustrative Factors and Indicators in Reducing Cost Risks

Factor	*Indicators*
• Design Simplification (Mission/Complexity)	- Mission simulation complete - 80% solution analysis complete
• Mature Manufacturing Processes (Cost/Yield)	- Scaleable process demonstrated - Statistical process controls in place
• Technology (cost trends, cost/performance)	- Product available - Market prices established
• Effective Integration (Errors/Redesign)	- 100% 3-D product model exists - Test articles available - Software available
• Commercial Processes and Components (Cost/Performance)	- Environmental suitability established
• DoD Prototype	- Integration verified
• Elimination of (unnecessary) DoD Unique Business Practices	- Low-cost business processes employed

B.7.2.3 Appropriate Metrics. It is critical to CAIV that the process of setting cost objectives begins as early as possible. The ability to set and achieve aggressive cost objectives depends significantly on early tradeoffs in performance versus costs. Metrics and observables are needed for an overall assessment of progress in applying CAIV to a collection of programs; to Defense Acquisition Executive (DAE) or Component Acquisition Executive (CAE) oversight of CAIV implementation; and to execution of the program. Illustrative metrics and observables are shown in Table B-7. In general, these identify important and observable steps that should be implemented in setting aggressive production and O&S cost objectives and then managing for their achievement. In some cases, quantitative metrics may be applied, indicated by the parentheses at the end of a process step. Specific risk reduction steps for manufacturing, performance, manpower utilization, etc., should be addressed by other metrics and observables. Implementation should be tailored for specific programs.

Table B-7: Illustrative CAIV Metrics and Observables

• Are cost objectives defined & consistent with programmed reqmts & projected fiscal resources?	- Out-year resources identified? ($) - Production and O&S cost objectives included in the RFP? - Key tradeoff issues addressed? (e.g., in COEA)
• Is DoD managing to achieve cost objectives?	- RFP contains a strict minimum number of performance specifications? (#) - CP-IPT functioning; tradeoff space identified in program baseline and RFP? - Risks to achieve cost objectives identified and program steps to address these defined? (risk plan) - Incentives for achieving cost objectives included in the RFP and contract? (% relative to total contract $'s) - Mechanism for contractor suggestions to reduce production and O&S costs in place and operating? - Robust contractor incentives plan in place?
• Are contractors managing to achieve cost objectives?	- Appropriate tools for cost-performance tradeoffs (including incentives for corporate management) and participates in cost-performance tradeoff process? - Identifying (and when appropriate implements) new technologies and manufacturing processes that can reduce costs? - Identifying procedural/process impediments to cost reduction measures? - Establishing strong relationship with vendor base, including sound incentives structure?

B.7.2.4 Motivating Management. Higher-level managers, program managers and industry must be motivated to innovate and accept increasing risks, and then be rewarded for achieving their objectives. Most importantly, they must not be penalized if failures occur, despite best management efforts. DoD must promote Congressional acceptance of this new way of doing business, even though open identification of risks might be used by those opposed to a program. Descriptions of two new incentives follow.

B.7.2.4.1 Motivating Government Managers. In the past, guidance to program managers have frequently not stressed up-front investments to minimize production and O&S costs. In the early phases, the program manager needs the encouragement of the users, CAEs, and the DAE to accept risks associated with aggressive cost objectives, and promotion policies must recognize and reward good tries as well as successes. Headquarters must accept risk taking (while promoting risk management) when the potential payoffs are high. In the later phases, the Defense Acquisition Board (DAB) and Component reviewers should enforce all aspects of life-cycle cost reduction, with increasingly specific exit criteria (identified in Acquisition Decision Memoranda) as the program evolves.

Effective top-level management should motivate managers and workers at every level to perform as desired by clearly identifying objectives and by fostering a positive "can-do" attitude from top to bottom. Promotion policies, awards and other formal recognition are important in providing feedback that jobs have indeed been done well. However, by far the best incentive for government managers is an environment that promotes goal setting, teamwork, and recognition of accomplishments from the management chain.

B.7.2.4.2 Motivating Industry. Motivating and incentivizing industry must center primarily on ensuring competition to win business along with attendant business profit in <u>all</u> phases of a program's life cycle.

Current practices frequently provide little or no industry incentive to reduce long-term costs to the government. Source selections all too frequently emphasize (near-term) performance, with less attention given to life-cycle costs. However, contractually incorporating production and life-cycle cost objectives and providing for a sharing of the savings when costs come in below objectives creates a "win-win" situation for all. The following tools and techniques are available to motivate contractors to reduce costs:

Competition: At both prime and sub-tier levels, the government should use competition for as long as reasonably possible. The government has maximum cost leverage when there are competing concepts or producers. In many cases, this means continuing competition as far into the acquisition cycle as practical and affordable, keeping open the option of re-starting competition in the production phase. (This must be planned for early in the acquisition process.) Therefore, cost objectives should be included in all RFPs, and the government should apply the results of cost/performance tradeoffs in contracts early in the process, preferably before final source selection. For industry, the early incentive is to win the business through the most credible solutions to the RFP problem statement that appear capable with acceptable risks of achieving specified cost objectives. Thus, contractors should be encouraged by program managers to incentivize sub-tier vendors to assist in cost reduction efforts, both through competition and other incentives.

Maximum use of open systems concepts at all levels can greatly facilitate having opportunities for continuing competition throughout program lifetime. When it is no longer practicable to maintain real competition for a system, some of the benefits of competition can still be obtained through competition among acquisition programs within the same mission area for available funds in the Planning, Programming, Budgeting System (PPBS) process.

Shared Savings Incentives: Value Engineering provides rebates of substantial percentages of savings to the contractor. Current obstacles to the use of value engineering include long administrative approval times and concerns over the possibility of product gaming. Judicious setting of objectives and thresholds under CAIV are needed to overcome these obstacles.

Contract Incentives: Well-structured contracts and well-designed contract incentive clauses are key in focusing contractor attention on cost reduction. The following considerations apply in the different stages of acquisition:

> <u>Development</u>: In early design with multiple concepts, competition is the government's strongest tool. The design and development contracts should include cost objectives for production and life cycle costs and require the accomplishment of cost/performance tradeoffs. The source selection criteria communicated to industry should reflect the importance of developing a system

that can achieve stated production and life cycle cost thresholds. We need credible models to track projected unit production cost and O&S costs through development and into production.

Production: A focus on first production lot quantities removes the effect of later quantity changes and can emphasize initial quality. When appropriate, an arrangement should be included in the contract that provides the contractor with a share of the cost savings for bringing the program in at or below objective price. Care must be taken not to sub-optimize the first production lot cost at the expense of O&S costs. For later production lots, the objective is to incentivize continued cost reduction throughout the production phase. When practicable, as discussed above, competition can be introduced if unwarranted price increases occur. Other tools that would further reduce costs during production include multi-year procurement contracts, component breakout, and value engineering-type clauses.

O&S: Incentives during early production and follow-on could be in the form of repair warranties with the contractor, or alternatively (possibly deferred payment) incentive fees could be tied to the R&D or production contracts. Since O&S costs are not easily measurable in the early stages of the acquisition process, incentives to reduce O&S costs may require a (validated) model that relates specific design parameters to measurable and predictable O&S costs. Reliability and maintainability characteristics, which are more readily measured and projected, might serve as early indicators of progress towards meeting O&S cost objectives. In any event, DoD needs better cost models for the O&S phase of our programs. We face the challenge that CAIV may involve incentivizing savings and cost avoidances that will only be realized in the more distant future.

B.7.2.5 Incentives for Fielded Systems. Two new programs have been recommended in this area. The first is to institute an *awards program* to recognize valuable suggestions toward reducing life-cycle costs. A board would be established to review nominations for the awards, which should be made at least annually. A second new incentive program would be established to encourage Component (Service) funding of high-leverage proposals for investments to reduce future life-cycle costs. Annually, the proposals would be ranked by projected, validated return-on-investment, risk, and other considerations. Participants from both Government and industry would be encouraged to compete for these resources. A suitable mechanism to fund as many worthy proposals as possible would be implemented.

B.8 Modeling and Simulation

B.8.1 Introduction. Modeling and simulation (M&S) tools have been in use for quite some time. In recent years, advances in information technology offer new opportunities for tools to aid the analytic and design communities. These new opportunities come from computers and communications that are much faster and affordable. Finer granularity models can be used that execute in the same elapsed time as did less precise, older models. Models and simulation are now used in every phase of a product, as shown in Figure B-8.

Simulations are becoming ubiquitous. They will be embedded in every phase of support tools for acquisition. The notion of interoperability has already taken hold; simulations built by different projects are engineered so that they can later be connected in federations with each simulation delivering a complementary capability. Because M&S applications span multiple functional areas, they should help achieve improved cooperation across DoD, foster an emerging consensus, and support a roughly common vision.

The conceptual model of the computer model mission space, or CMMS, is a complex database which provides a shared authoritative understanding of the real world. It is multi-dimensional and depicts the entities, actions, and interactions that occur in the real-world. Such a resource will provide an evolvable and accessible framework of information to support the front-end analysis that must be done as part of any simulation design process.

Common data standards include the development of common data interchange formats, identification of authoritative data sources, and guidance for verifying, validating and certifying data; thereby facilitating access to required data and ensuring database quality.

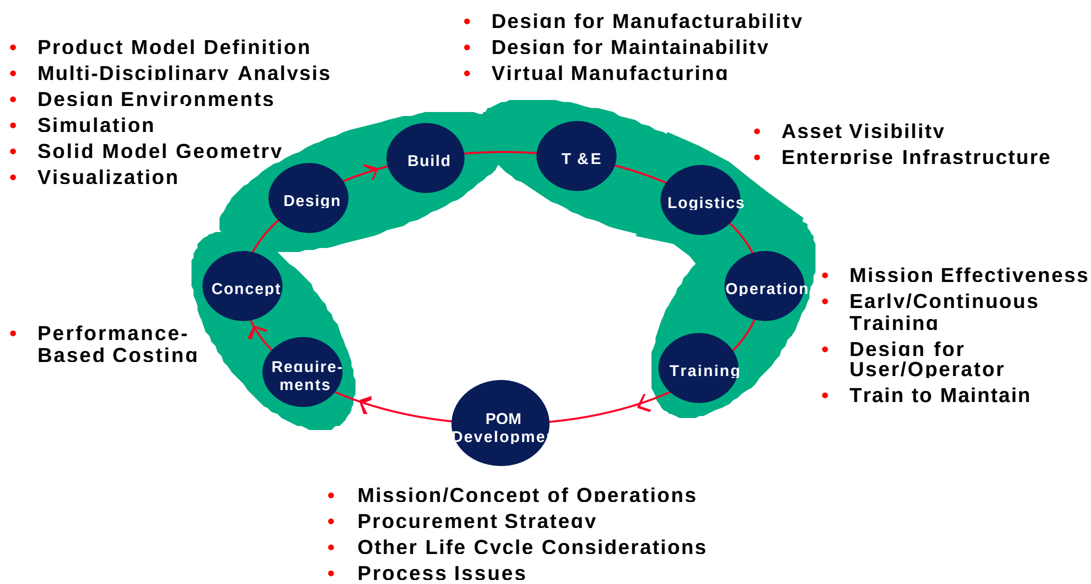

Figure B-8. Use of Models and Simulations in Various Life-Cycle Phases.

The benefits of using the new capabilities of simulations are:

- For developers - adaptable architectures with a full range of scale and complexity saving cost, schedule, and risk for the same level of requirements.
- For users - new federations to answer different questions with greater granularity.
- For resource sponsors - no need to fund as many upgrades to meet new requirements.
- For DoD leadership - development of fewer simulations and more capable and adaptable existing simulations.

The Defense Modeling and Simulation Office (http://www.dmso.mil/) has made great strides in developing a consensus-building forum within the DoD modeling and simulation community. For example, the creation of three functional area councils, under the Executive Council for Modeling and Simulation, provide stakeholder representation within the functional communities of analysis, acquisition, and training. The initial task for the three councils is to build annexes for their respective functional areas for the DoD Modeling and Simulation Master Plan that spell out that community's priorities. The Analysis Council is available to the analytic community to influence and develop priorities and statements of what is important to the analytic community. Representatives of the Office of the Secretary of Defense / Program, Analysis and Evaluation (OSD/PA&E), and the Joint Staff jointly chair the Analysis Council.

B.8.2 Simulation Based Acquisition. The new 5000-series acquisition regulations strongly encourage the use of models and simulations to improve quality and to reduce acquisition time, resources, and risks. They also encourage embedding virtual prototypes in synthetic environments to support requirements definition, concept exploration, and manufacturing and testing of new systems.

The Defense Department envisions an acquisition process supported by the robust, collaborative use of simulation technology that is integrated across acquisition phases and programs, as shown in Figure B-9. This vision is called Simulation Based Acquisition (SBA). The objectives of SBA are to:

(1) Reduce the time, resources, and risk associated with the acquisition process
(2) Increase the quality, military utility, and supportability of systems developed and fielded
(3) Enable integrated product and process development from requirements definition and initial concept development through testing, manufacturing, and fielding

Substantial evidence has already accumulated regarding the value of a simulation-based approach to acquisition. Both commercial and military programs provide pervasive evidence of tangible results that can be measured in terms of improvements in *cost, schedule, productivity,* and *quality/performance*.

Simulation Based Acquisition is comprised of three principal components. The first is an *advanced systems engineering environment* that uses formal methods and automation to support efficient design synthesis, capture, and assessment, as well as other complex life-cycle activities.

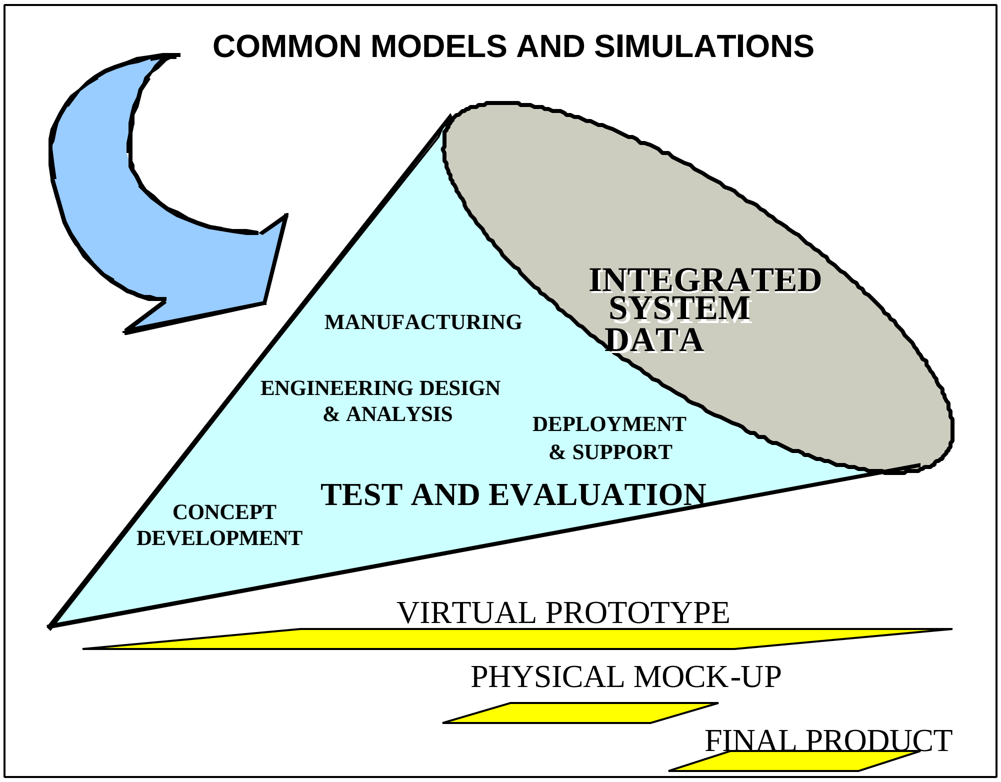

Figure B-9. Integrating Models and Simulation Within and Across Programs.

The SBA engineering environment provides a means for executing a process that can be extended, tailored, and repeated. The process results in the creation of reusable design repositories and products that can be reengineered. The potential gains from the use of such an advanced SBA environment will not be realized until the engineering process, as well as its people and organizations, also evolve.

The second component is a *refined system acquisition process* that takes advantage of the SBA systems engineering environment capabilities. The third component is a culture that has evolved to a point where *enterprise-wide cooperation* is the rule, and individual technical contributions and innovations are encouraged and managed efficiently.

Simulation Based Acquisition *is not an incremental step* beyond current system engineering methods and tools. Instead, it represents *a major paradigm shift* toward a comprehensive, integrated environment that addresses the entire system development life cycle and the spectrum of engineering and management domains.

B.8.2.1 M&S as a Decision and Management Tool. Decision cycle times are improved when program managers and functional staffs have access to modeling and simulation results. Models and simulations also allow the program manager to measure and track performance against milestone decision criteria. A virtual factory can be developed to evaluate the producibility of a design and initiate tooling design at an early stage of the program. By identifying the maintenance and supply requirements associated with a design, a program manager can exert positive front end control over the system's logistics "footprint" and life cycle cost.

The ability to develop digital master product models with Computer-Aided Design/ Computer-Aided Manufacturing/Computer-Aided Engineering (CAD/CAM/CAE) software technology has made it possible to more fully understand products from a manufacturing standpoint during the early design stage. The depth and richness of the product information contained in a digital master model makes it easier to more fully communicate detailed information to everyone involved in the product development process.

B.8.2.2 M&S in Design. Digital master models help to develop and evaluate multiple design concepts so that the material solution most efficiently meets user needs. Quality becomes part of the design process itself and can be built-in instead of added-on. Digital master models provide details about the product's shape, behavior, and cost before the fabrication of costly physical prototypes, and help minimize scrap, reduce downtime, and eliminate wasted or redundant operations. This approach allows teams to work concurrently by providing common ground for interrelated product development tasks. Instead of individuals creating one piece of information at a time, the digital master model enables various disciplines to work together much earlier in the product development process.

B.8.2.3 M&S in Manufacturing. Use of standard, relatively inexpensive computer equipment, virtual prototypes and simulations helps to bring together a shared vision of the system and provides a means for understanding the complex interactions among the configuration items in the system design. Some studies indicate that the use of computer aided design/manufacturing (CAD/CAM) tools and common databases can result in significant manufacturing cost avoidance, including:

- 20-60% reductions in set up time
- 15-25% reductions in planned labor and tooling
- 15-75% reductions in rework and scrap
- 20-50% reductions in work-in-progress carrying cost

The primary contribution of emerging M&S tools is not in improved manufacturing technologies, but rather in bringing manufacturing expertise to the design processes so that the final design is more manufacturable. Improved manufacturability offers significant potential payoff.

In addition, M&S tools can assist the manufacturing team in designing the manufacturing process for a new system just as the design team is developing the design. The equipment, work flow, and overall process for manufacturing can now be developed and analyzed in a virtual environment with high confidence in the results.

B.8.2.4 M&S in Test and Evaluation. At a minimum, the early involvement of the T&E engineer in the concept development stage, to ensure that functional requirements are formulated in a testable manner, is facilitated and aided by M&S tools. Similar tools are now widely used to plan, rehearse, extend, and evaluate live T&E activities. To a significant extent, assessment of a system is now possible using M&S long before a physical prototype is actually constructed. Physics-based dynamic models using CAD descriptions of the system in a test-validated environment now provide critical feedback to system designers, as well as users, as the design matures.

For example, the first flight of a new aircraft is preceded by years and hundreds of millions of dollars of mathematical modeling, flight simulations, hardware-in-the-loop (HWIL), software-in-the-loop (SWIL), and other simulations.

As in previous phases, the significant change made possible by the use of M&S tools is to integrate these O&S functions into the total system development process. That primarily means considering the implications of these functions on the concept which is selected and the design which is developed to satisfy operational requirements. Not only can operational use be evaluated during the design stages to minimize the subsequent necessity for modifications to the fielded systems, but the support requirements for those systems can be better analyzed during the design stage to lessen the support burden and thus the total life cycle costs of the system.

The real power of a computer based modeling and simulation system lies in the connection and coordination between the tools and functional users. Systems that provide a seamless environment for geographically distributed teams and a diverse set of functional users will tend to lead to cost avoidance on the higher end of the reduction ranges just described. In addition to increasing the effectiveness of the design and manufacturing functional specialists, the product support members (testers, logisticians and maintainers) of the team will benefit as well.

The bottom line is that integrated product and process development, backed by a strong commitment to computer based modeling and simulation tools, provides a dominant competitive edge in the commercial marketplace and a clear warfighting edge on the battlefield. It provides a path for getting to market first and at a lower cost.

B.9 An S&T IPPD Process

B.9.1 Implementing the IPPD Process

The basic functions associated with implementing IPPD principles are shown in the process diagram in Figure B.10. This process was originally developed by the U.S. Air Force in conjunction with approximately 30 companies in the defense aerospace industry. While the process is displayed horizontally to make it easy to read, it is *not* a serial process, as the large elliptical background arrow suggests. The main activities associated with the process are represented by the central six blocks. The document symbols along the bottom represent important outputs from the process. The artifacts along the top of the diagram represent various methods and tools which can be employed to implement the process.

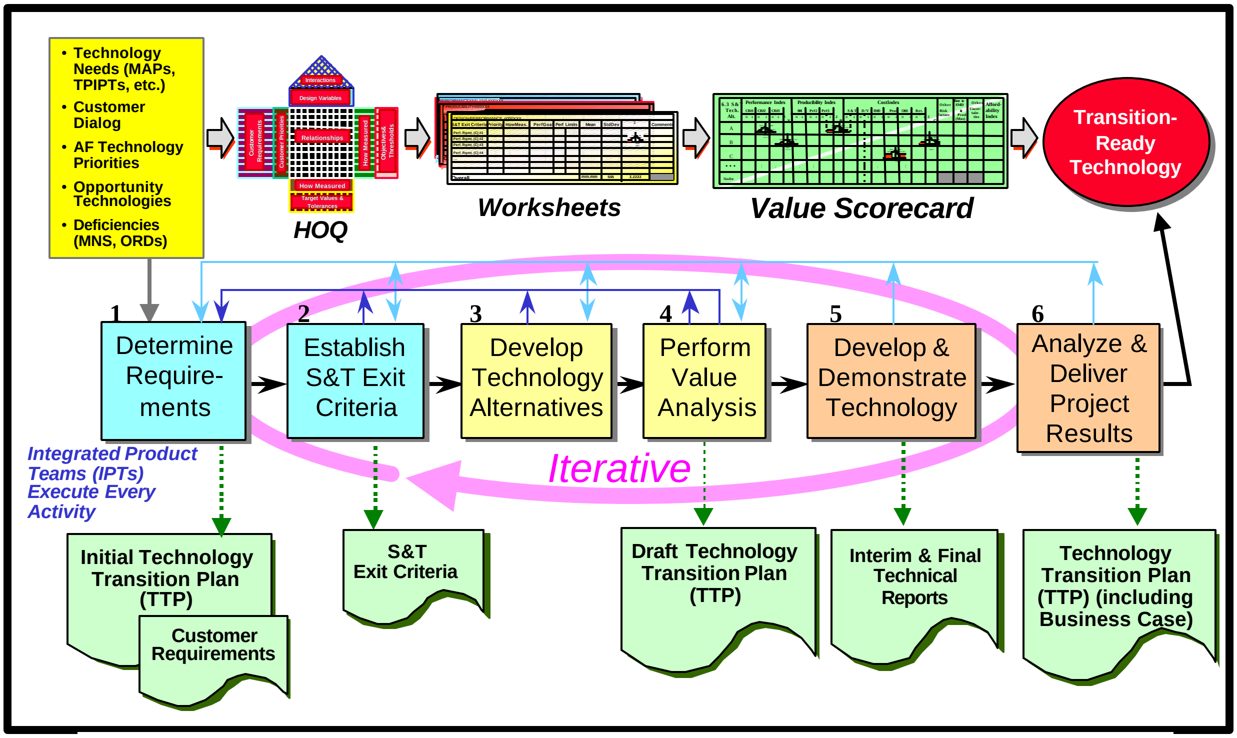

Figure B.10. An S&T IPPD Process

During a workshop in 1994, when this process was first contemplated, it became apparent to everyone present that IPPD is not something that can be layered on top of an S&T development effort. Rather, *one either develops technology in an integration fashion, or one does not*. As that workshop, industry experience, and subsequent experience with S&T IPPD Pilot projects have demonstrated IPPD is *not something you do in addition to S&T*. It is a fundamental way of thinking about and executing technology development. There is not one set of program goals and another set of IPPD goals. They must be one and the same. They must address the critical issues associated with technology maturation and transition (viz. producibility, life-cycle cost and risk). It should be noted that if transition issues to the next phase of development are not addressed as explicit program requirements, the program is *not* addressing IPPD issues, regardless of the use of a team approach. The process in Figure B.10 provides a structured approach for addressing those critical issues, namely, the balance of performance, producibility, cost and risk, and making those elements integral to an S&T effort.

The six activities outlined in the integrated technology development process in Figure B.10 are each briefly described below.

B.9.1.1 Define Requirements

The process begins with defining the requirements. The activity of defining requirements requires (i) one or more customers, explicitly identified and participating in the process, and (ii) the participation of *all* stakeholders, from S&T personnel and customers to designers, production and manufacturing, logistics, financial and others. Hence, it is imperative to form an integrated product team (IPT).

IPTs are critically important if life cycle and support issues are to be considered early in the design process. If the IPT is successful, the result will be a more mature technology that requires fewer costly changes later in the product development process. A successful IPT achieves the benefit of reduced cost and schedule while maintaining and often increasing the quality of a technology. As industry experience has demonstrated, quality tends to cost less, not more. The same is true in S&T. IPT activities during 6.3 and advanced technology demonstrations should focus principally on the warfighter customer and meeting that customer's need, although laboratory and technology base needs should not be neglected, particularly in 6.2 and early 6.3 efforts. Accurately understanding the various levels of user needs and establishing realistic requirements that will enable the technology to transition smoothly into the acquisition cycle is critical to achieving affordable technology. The criteria for developing a good IPT that focuses on strong customer involvement are discussed in detail under Section 2.2.2 .

Defining requirements involves looking at a problem from multiple perspectives. Different requirements are often associated with different customers. For example, end-users generally specify performance and life-cycle cost requirements. Industry team members, who will be focused on manufacturing the system or sub-system, might be equally concerned with producibility issues. The logistics people, who will need to support the system or sub-system once it is fielded, will be concerned with supportability requirements. The laboratory itself may have requirements for longer term technology development to meet emerging threats that are not yet on end-users' radar screens.

Requirements can be documented in a matrix as shown in Figure B.11, which is a partial "snapshot" of a spreadsheet based tool for capturing S&T requirements. We focus initially on the first five columns (through "How Measured"). Indeed, it is the "How Measured" column that is perhaps most important.

In order to accurately describe where we are and where we are going, a metric (or a set of metrics) is needed. The purpose of establishing specific, quantifiable measures for each requirement is two-fold. Measures enable:

a. Assessment of when, and to what extent, we have satisfied the requirements

b. Predictive comparisons among competing technologies

Advanced Laser Eye Protection

Top-Level Requirements Matrix

Updated: 26 Aug 98

d	Customer	Requirement	Pri	How Measured	Objective	Lower Threshold	Upper Threshold	Type
Protection, Source Confguration 1								
1	HSC/YA	Daytime Disability Glare, Source Config 1	High	Corneal Illum, ANSI MPE [CW, µW/cm^2 @ 530nm]	0.1	N/A	0.15	A(perf)
2	HSC/YA	Nighttime Disability Glare, Source Config 1	High	Corneal Illum, CW, µW/cm^2 @ 530nm (photopic)	10	8	12	A(perf)
3	HSC/YA	Daytime Flash Blindness, Source Config 1	High	Log Troland Seconds, not to exceed daytime equiv bkgnd	1.5	N/A	3	A(perf)
4	HSC/YA	Nighttime Flash Blindness,Source Config 1	High	Log Troland Seconds, not to exceed nighttime equiv bkgnd	1	N/A	3	A(perf)
5	HSC/YA	Permanent Eye Damage, Source Config 1	High	ANSI MPE	0.5	N/A	1	A(perf)

Figure B.11. Example S&T Requirements Matrix (Partial, courtesy USAF AFRL)

Readers familiar with techniques such as *Quality Function Deployment* (QFD) will notice certain differences between the matrix in Figure B.11 and traditional QFD *House of Quality* approach. The matrix above has been tailored to meet the needs of S&T. Each requirement is associated with one or more specific measures. The level of requirements detail shown above should not be confused with that of a typical Operational Requirements Document (ORD) or even with a statement of work (SOW). This approach can be used to address almost any level of requirements, from strategic down to detail design. The requirements in Figure B.11 reflect the level of detail needed to assess affordability, in terms of best value across performance, producibility, life-cycle cost and risk, for one or more specific laser eyewear technologies. Although not shown, these requirements are mapped to the ORD/end-user level requirements.

Experience reveals that the real work begins with defining the measures. In actual S&T Affordability Pilot programs, defining the measures has resulted in several important benefits:

a. Measures clarify the requirements. Quite often the ensuing discussion about the metric causes IPT members to clarify the definition of the requirement, thus eliminating ambiguity. *You can't measure what you can't clearly define.*

b. Measures provoke an *exploration* of the requirements. Often a requirement is more complex than we first imagine. It may require several parameters to properly measure it. Figure B.11 provides an excellent example. The five requirements shown in Figure B.11 began as a single requirement: "Provide protection against Source Configuration 1." ("Source configuration 1" is of course clearly defined elsewhere.) In the ensuing discussion, what was originally thought to be a single, well-understood requirement for laser eye protection evolved into *five* requirements, each with its specific measure.

c. Measures drive IPT consensus. In the example in Figure B.11, the IPT consisted of SPO customers, engineers, optical filter (thin film) scientists, end-user representatives, fabricators and human systems scientists. Initially, opinions varied widely in terms of how to measure optical protection against laser threats. The first cut at protection metrics resulted in a simple optical density (OD) measure. However, ensuing discussion soon revealed that OD was not a good measure because it is too ambiguous and does not reflect potential eye damage levels. Issues such as laser pulse rate also confound the problem. At first, there were clear divisions of opinion between the optical filter experts and the human factors scientists who actually study biological effects and eye damage. Through facilitated discussion and over the course of several meetings, the differences were resolved. A new, far more meaningful set of metrics was established that satisfied all of the disciplines. The ability to measure progress and results became far more robust than in the past.

d. Measures sometimes drive the science. For example, in the laser eye protection area, everyone on the team recognized the value of objective metrics that can be assessed quickly and cost-effectively, in a laboratory bench setting, as opposed to more subjective measures based on human or bioeffects sampling. However, when objective measures address human factors issues, they must be correlated with actual bioeffect and/or perceptual data. The measures may therefore require correlation studies and in that sense, they can influence the science investment.

e. Measures enable affordability assessment. Throughout the laboratories and industry, there has been a growing call to be able to assess the affordability of a new technologies (i) with respect to performance, producibility, cost and risk, (ii) in a way that is *objective* and *quantifiable* in addition to capturing relevant subjective information, and (iii) in a way that engenders *confidence* on the part of technology recipients (S&T customers) so that laboratory claims are *credible*. Credibility is engendered by the exercise of a *process* and by achieving *measurable results* that are *traceable* from the final affordability assessment right back to the original driving requirements.

B.9.1.2 S&T Exit Criteria

S&T Exit Criteria are the *objectives and thresholds* associated with quantifiable metrics (the *measures)*. They are used to estimate future affordability, track technical progress and ultimately to characterize the affordability of new technologies. We begin to establish “exit criteria” when we establish specific objectives and thresholds for all high priority requirements. Notice in Figure B.11 that requirement #1, Daytime Disability Glare, Source Config 1, is measured in terms of ANSI MPE (Maximum Permissible Exposure). The objective is to achieve 0.10 or one tenth ANSI MPE (a specific, published value). There is no lower threshold, indicating that “less is better.” The upper threshold, that is, the value beyond which the protection fails to meet the requirement, is 0.15 ANSI MPE.

To help establish objectives and thresholds, as well as support subsequent affordability analysis, *Desirability Curves* can be developed in consultation with the IPT. An example of the desirability curve for Daytime Disability Glare is shown in Figure B.12, (another example of a worksheet based tool to support S&T). The desirability chart plots desirability (d) on the y-axis as a function of the parameter of interest (x-axis). The *objective* for the requirement is represented by the left end of the curve, while the threshold (in this case, an *upper threshold*) is represented by the right side of the chart. The desirability number ranges from 0 to 1 on the y-axis.

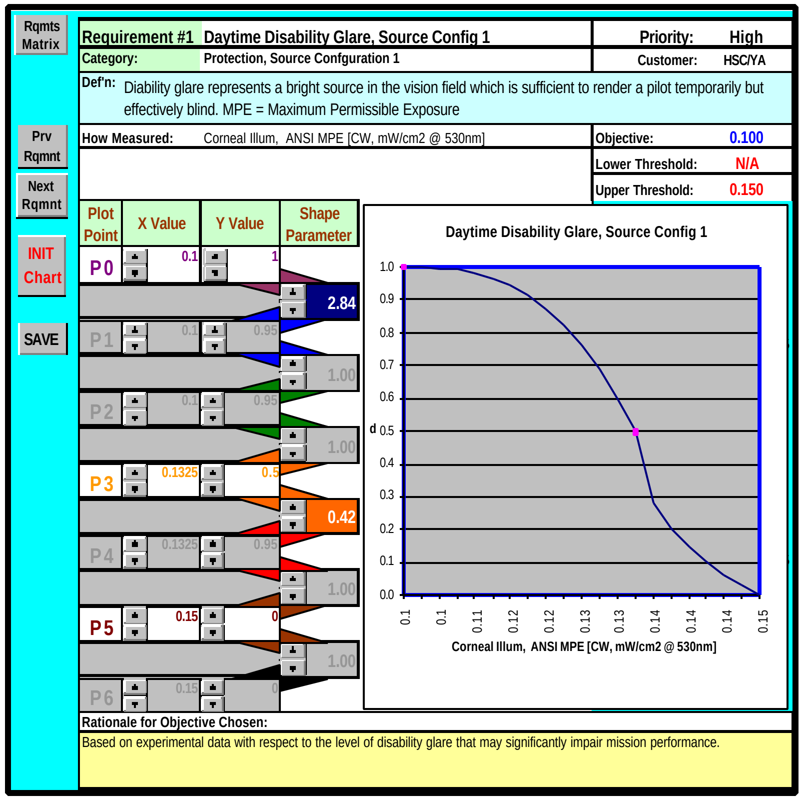

Figure B.12. Establishing Desirability Curves

One of the important benefits of thinking about requirements in terms of desirabilities is that it promotes discussion with the customer concerning threshold negotiation. Thus, it helps the team reach consensus on the *real* requirement, the *must have* rather than the *nice to have.* It also provides considerable insight with respect to the customer's perspective on each requirement, based on the shape of the associated curve. Experience shows that in many cases, customers (end users) do not know what is *feasible*. They do not know what the technology is capable of doing. The discussions that arise from a consideration of desirabilities often help customers and technologists reach consensus on what the real requirement *should* be, based in part on what the technologists believe is the technology potential.

Once established, the *thresholds* of all high priority requirements represent the S&T Exit Criteria for the program. If those requirements have been negotiated with S&T customers, the thresholds collectively reflect the level of technology maturity, in terms of performance, producibility and life-cycle cost and risk, required by the S&T customer to deem the technology ready for transition. If desirability curves have been established for all key performance, producibility and life-cycle cost requirements, the desirability values for each requirement, along with their associated weights, can be combined using a weighted geometric mean to provide an overall customer satisfaction index (CSI). The CSI is a useful metric that reflects the collective extent to which a given technology will (predictive) or has (measured) satisfied the Exit Criteria and is therefore a useful approach for estimating (predictive or measured) overall technology maturity.

B.9.1.3 Technology Alternatives

The third activity associated with the IPPD-driven technology development process (Figure B.10) addresses the issue of defining technology alternatives. Technology alternatives represent various technology configurations, solutions, systems and/or sub-systems that can be developed and combined in an effort to satisfy the Exit Criteria. Technology Alternatives are addressed at three distinctly different levels:

a. Strategic: Addresses issues among competing mission scenarios at the system level (e.g. piloted or uninhabited vehicle? Smart skin or low-cost expendable?).

b. Tactical: Addresses issues among competing technology alternatives at the sub-system or fabrication process level, generally based on expert analysis and consensus (e.g. the strategic decision might be to develop infrared countermeasures, the program level addresses trades between competing laser technologies, or, it might be to assess the affordability impact of various processing technologies for advanced composites)

c. Detailed: Addresses issues among competing designs or fabrication processes to enable improved design optimization and a better search of the *design space*. It is based on detailed analytic, response surface and multi-variable design optimization techniques (e.g. specific competing designs are optimized within their individual design spaces using techniques such as response surface analysis [Figure B.13], and then evaluated with respect to expected performance, producibility, life-cycle cost and risk)

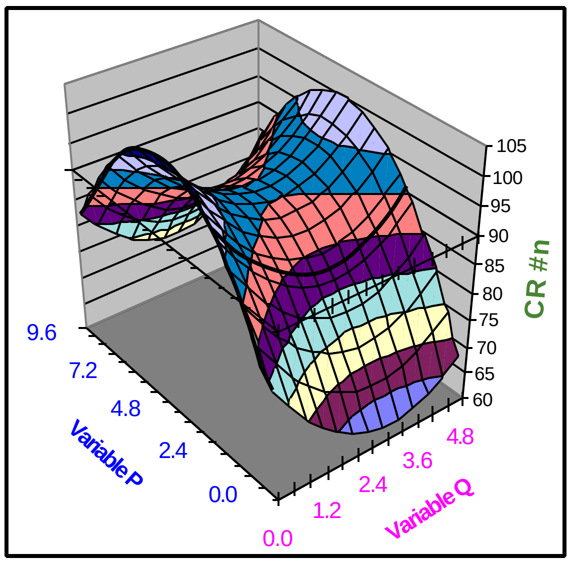

Figure B.13. Example of *design space, response surface* analysis, 2 variables vs response.

Many of the methods discussed in this document that support the process shown in Figure B.10 can be applied at the strategic assessment level. However, our focus here is on the 6.3 project level, on the tactical and detailed technology development scenarios. These levels are not completely independent. Strategic system affordability cannot at times be adequately assessed without some roll-up from a lower level analysis at the sub-system, *tactical* level. Likewise, affordability assessments at the tactical level lack the fidelity of more detailed analyses unless those detailed design space analyses are performed and rolled up to the tactical level.

The depth and fidelity of the analysis at any level depends in part on time and budget, and in part on the design expertise of the team. Industry experience has shown, for example, that a detailed, multi-variable, concurrent design space and design optimization approach, while it may at first *appear* to require more work than a traditional serial design approach, can be far more efficient, because it can sidestep the costly and time-consuming pursuit of dead-end paths. Indeed, the gains have been so great, that this approach has become *de rigueur* at several leading companies.

It was stated earlier that development decisions made very early in the design process have a major impact on future system cost. It follows that we can maximize the payoff in terms of future system affordability at this phase, *if* we can cost-effectively improve the quality and fidelity of our technology assessments. Better assessments lead to better investment decisions. When we *know* what the transition cost and risk drivers are, then we can address them. In order to make the right decisions early, however, we need to be able to *predict* how the various technology alternatives will likely perform against a given set of Exit Criteria.

When we are considering technology alternatives relatively early in the process, the analysis should be conducted to the maximum level of detail and fidelity that we can reasonably tackle. If detailed design information, design variables, and/or high-fidelity models and simulations exist (and they often do in late 6.3), then a detailed design-space analysis and technology assessment can yield big dividends. If, however, it is necessary to assess a number of very different technology solutions (e.g. gas vs. semiconductor vs. fiber lasers), where we do not have adequate simulations or access to the design variables associated with the different technologies, then other approaches such as expert estimation and consensus techniques are in order (Figure B.14). While these techniques are not as rigorous or high fidelity as detailed design or simulation-based analyses, they are nevertheless extremely valuable in guiding technology investment decisions.

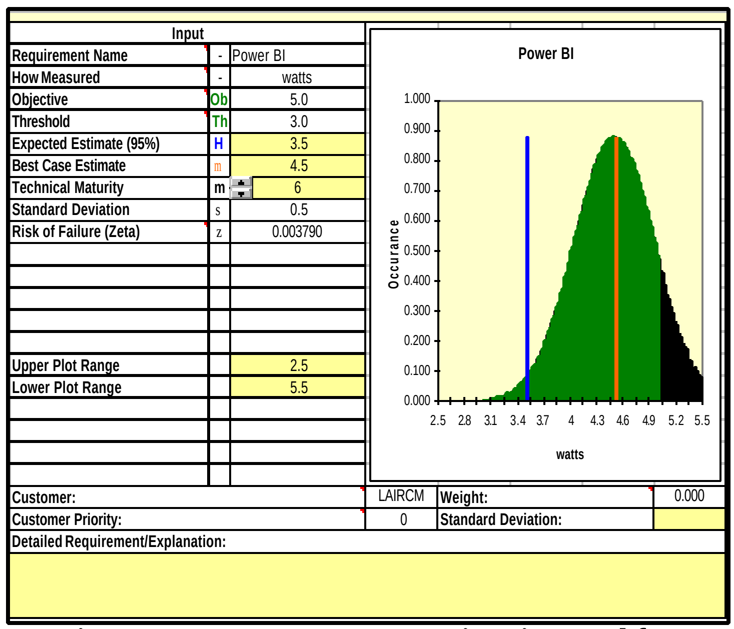

Fig B.14. Prototype Expert Estimation Tool for Affordability Assessment

Technology affordability can be assessed using one or more teams of experts supported by appropriate methods and tools to develop a consensus with respect to how each technology will likely perform against each of the Exit Criteria. Deciding *which* technology solutions or alternatives to assess in the first place is an inexact science. It requires that laboratory and industry personnel be aware of the possibilities. It often requires threat assessments and technology capability assessments to determine what is feasible within given time frames (e.g. 3, 5 and 10 years).

Tools and methods which are analogous to the Desirability Function tool shown in Figure B.12, but which address issues such as "probability of success" versus performance against a given criterion at a given point in the future, can be used to facilitate the estimates. Methods such as the Analytic Hierarchy Process (AHP) and Successive Proportional Additive Numeration (SPAN) can be used to achieve expert consensus even where there may be dissension within the team.

B.9.1.4 Value Analysis

The fourth activity shown in the process represented in Figure B.13 is Value Analysis. The decision to invest in a given technology is based on the extent to which we expect it will be able to meet or exceed a set of Exit Criteria within a certain time frame. The *risk* associated with those estimates can be characterized in terms of a *probability of failure* which, if the analysis is done properly, can be estimated using best practice techniques (viz. six sigma quality methods) borrowed from industry. In that case, the industry metric for new products, called First Time Yield (based on the probability of defects) is analogous to a First Time Success estimate for technology prototypes which is based on the probability of failure.

The results of a Value Analysis can be captured in a Value Scorecard (Figure B.15).

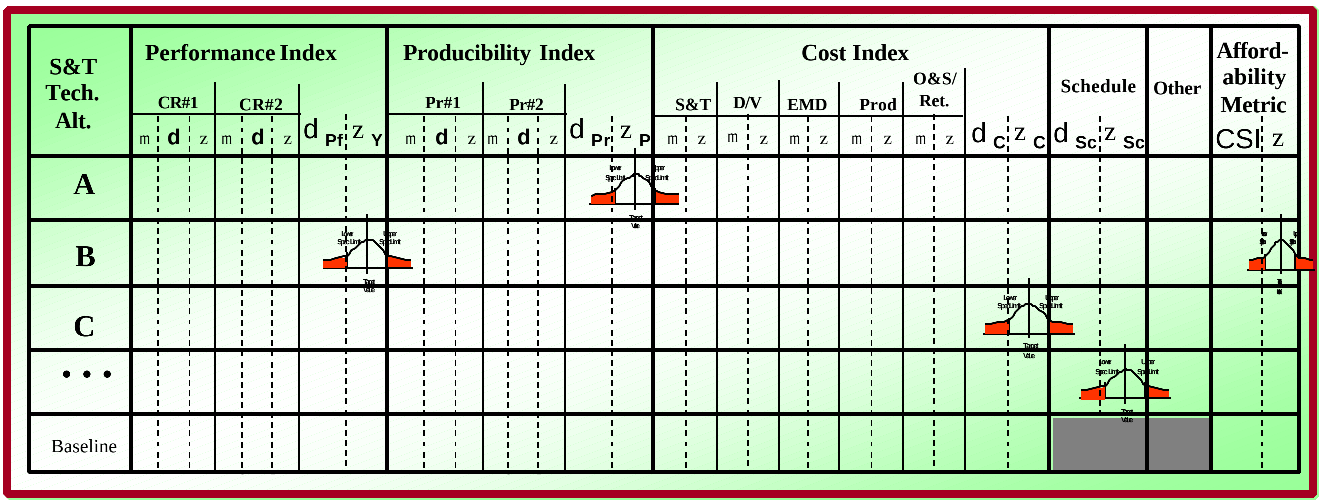

Figure B.15. Value Scorecard

The S&T Value Scorecard shown here is divided into five general areas, Performance, Producibility Cost, Schedule and Other. The two rightmost columns contain two affordability metrics, a Customer Satisfaction Index and an overall risk of failure (zeta). Within each of the general areas, such as Performance, there are columns associated with customer requirements (CR#1, CR#2, which correspond to exit criteria). Note that in the producibility area, the requirements have to do with producibility requirements (PR#1, PR#2, etc.). Within each requirement column there are three sub-columns designated as "mu" (μ), "d" (d), and "zeta" (ζ). The technologies of interest are designated on the left and each technology alternative, A, B, or C, corresponds to a scorecard row. As discussed earlier, mu represents the value that experts and designers think they can achieve with a given technology. This expected value may be an expert estimate, or it may be based on a design analysis.

These estimates are firmed up as much as possible as the technology proceeds through its development cycle.

The desirability and risk metrics were explained earlier. On the right end of each of the general areas, there are two columns that correspond to the area *index* (viz. the *Performance Index*, the *Producibility Index*, and the *Cost Index)*. Each of these indices consists, again, of two metrics, a composite desirability (d) and risk (ζ). It is important to note that cost issues can be addressed in the same way, and on the same terms, as performance and producibility issues. Experience suggests that schedule risk should be handled in the traditional manner and is related to the overlap of the S&T deliverables with the transition window. Other, less tangible but important risks, such as issues in foreign sourcing, are addressed in the *Other* column.

In the case of performance, producibility and cost, the actual numbers that populate the scorecard are derived from underlying documents. The approach in industry, and in the tools that are under development to support this process, has been to develop the supporting data in performance, producibility and cost worksheets. The worksheets are supported by underlying design, producibility and cost analyses. A number of different methods may be employed to perform these analyses, including desirability analysis, designed experiments, response surface analysis, models and simulations, process capability analysis, cost models and expert consensus.

Often, several scorecards are developed during the course of a program. A preliminary scorecard, based principally on expert consensus, might be used to perform a higher level technology assessment. A detailed scorecard, based on actual design variables, models, simulations, statistically designed experiments and response surface analysis might be developed to support investment decisions for a specific technology or critical sub-system component. It is important to observe that the scorecard can be a powerful and effective affordability tool regardless of the level of abstraction or detail available to the analysis. It can be developed fairly quickly and inexpensively to provide credible but rough order-of-magnitude estimates, or more time and effort can be devoted to a higher fidelity, more substantial analysis.

There are many benefits that result from using these metrics in S&T, and there are additional benefits that result from developing and populating a value scorecard. Some of those benefits include:

a. The desirability (d) and risk (ζ) metrics transcend very different areas (performance, producibility and cost). Hence, they provide a capability to assess *overall value* as a function of those areas.

b. By using two metrics, an *affordability vector* is developed. What results from the desirability metric is a sense of how a technology stacks up in the customer's eyes, when all of the customer requirements and the importance (weights) associated with those requirements, are factored in. The risk indices and the overall risk provide a quantified roll-up of the accumulated risk, building it up from individual requirements level.

c. Because of the process, cost and risk drivers are fully traceable right down to the original requirements, design parameters, analytical assumptions, and other factors. The scorecard itself enables project managers to quickly identify cost drivers and locate their origins. And, because the indices associated with each area are built up from the underlying worksheets, which contain *all* of the requirements, rather than the limited set selected for display in the scorecard, any serious discrepancy between the displayed requirements and the indices points to the fact that one must dig deeper (into the worksheets) to understand the issue.

d. The Value Scorecard enables better, more defendable technology investment decisions. Without exception, every pilot project that has engaged in this process has benefitted from the outset, beginning with a requirements analysis that includes identifying the measures, objectives and thresholds. The scorecard represents the denouement of that process, a bottom line assessment of how each technology stacks up against the S&T Exit Criteria. The scorecard *does not make the decision*, however. Rather, it provides the information required to make the decision. That information can support the use of other tools, where methods such as the eigenvector (analytic hierarchy process) can support a formal decision-making process.

B.9.1.5 Technology Development.

The fifth activity in the process shown in Figure B.10 is the technology development effort itself. During technology development, the methods and estimates that were used in the preliminary value analysis are revisited. Scorecard estimates are refined as more data become available and confidence in those estimates improves. As the program proceeds, it may become obvious that certain exit criteria will or will not be met. One of the strengths of using a scorecard approach is that exit criterion is traceable back to a specific customer requirement. If the program is being managed using an IPPD approach, *the customer is still involved during technology development*.

Because the path from requirement to scorecard metrics is fully traceable through underlying worksheets, it is possible to rapidly and cost-effectively perform various impact analyses. Impact analyses reveal the overall impact on system performance, producibility and cost that may result from changing the objectives and thresholds associated with individual requirements. Hence, thresholds and desirability curves can, at any point, be revisited with the customer, and, given access to appropriate software tools, the impact of changing thresholds on scorecard performance, producibility and life-cycle cost parameters can be seen immediately in the scorecard, and in the affordability roll-up metrics (customer satisfaction and overall risk).

B.9.1.6 Technology Delivery

The final activity in the process shown in Figure B.10 addresses the final analysis and delivery of the project results. The analysis is captured in the *business case* portion of the Technology Transition Plan (TTP). In the context of this process, the TTP is viewed as a *living document*. It evolves over the course of the project, and includes the results of the value analysis, including the scorecard. Once the project is complete, the TTP serves as a transition document, detailing the performance, producibility and life-cycle cost issues, and discussing the overall affordability of the technology in terms of the extent to which it satisfies the exit criteria. The results of the program are cast in terms of the customer's language and perspective. All claims regarding performance, producibility and life-cycle cost are supported by the underlying analysis.

B.9.2 Summary

The IPPD process and methods outlined here provide a structured, measurement-driven approach to technology development. They can be employed at a high level of abstraction, or at a detailed design level. They can drive technology development. For example, even early in the technology development process, knowing the type and fidelity of the information that will be needed down the road in a value analysis can drive the input and output requirements for a modeling and simulation effort. Often, in order to measure a given requirement, correlation studies must be performed to establish the relationship between objective laboratory measurement and human perception.

IPPD is not an add-on. It must be comprehensive and intrinsic to the effort, *a way of doing business.* The process and methods described here help substantially in providing a framework in which to proceed with an IPPD-driven technology development effort.

APPENDIX C

DoD S&T AFFORDABILITY PROGRAMS
(1997 - 1999)

1997 - 1999 S&T Affordability Programs

On an annual basis, fifteen to twenty tri-Service/DARPA affordability programs are identified and evaluated on how well they meet the defined affordability criteria (described in Section 2). These 6.2/6.3 programs represent S&T projects from many different technology areas as identified in the Defense Technology Area Plan. The results of the S&T Affordability Task Force review are presented during to the Defense S&T Advisory Group (DSTAG), the senior service/agency body that develops S&T policies and priorities. A listing and brief description of how these programs addressed affordability issues follows.

AIR PLATFORMS DEFENSE TECHNOLOGY AREA	
Advanced Motor Drive (1997)	Four year, $3.8M Air Force CRDA (with $4.0M cost share by Sunstrand) to design, fabricate and test a 270 VDC electromechanical actuator (EMA) for a spoiler surface of a transport aircraft. It is to achieve double (1 kW/lb) the power density of present day systems with 81% efficiency. Notable affordability practices: • IPT established (with participation from Boeing, Sunstrand, C-17, C-5, B1B & ManTech). • Cost sharing of program developmental expenses by contractor. • QFD and HOQ being used.
Tier II+ High Altitude Endurance Unmanned Air Vehicle (1997)	DARPA-sponsored ACTD initiated in 1990 to respond to a JROC request to develop a high altitude, long endurance, reconnaissance, survivable, target acquisition (RSTA) systems for theater area defense. Users are USACOM, ACC and ASC. Notable affordability practices: • IPT key driver of program management approach. • Maximum use of COTS (very few mil-specs). • $10M unit flyaway cost driving performance tradeoffs (CAIV). • As ACTD, DARPA has applied section 845 “other agreements” authority, which avoids the DoD 5000.1 acquisition & contractual requirements. This motivates contractor to provide more affordable product that maximizes performance. • Extensive user involvement with 24-month user operational field demo requirement. • Parallel affordability program exists in agile logistics to address reduction of life cycle cost and part count. • Transition team in place with a plan to be established in FY98.

AIR PLATFORMS DEFENSE TECHNOLOGY AREA (CONT'D.)	
Miniature Air Launched Decoy (1997/1998)	DARPA ACTD ($26M) with Teledyne Ryan to develop a launch vehicle decoy. The objective of the program is to build a miniature air vehicle that mimics aircraft or weapons with a $30K average unit fly away cost goal at unit 3,000. The F16 is the vehicle in which the technology is to be demonstrated. Details on this program are found in Section 3.4.
Rotary Wing Structures Tech Demo (1997/1998)	The Army's Comanche is the combat demonstration vehicle for transition of this new composites technology that focuses on reducing weight and strengthening military vehicles while developing more efficient manufacturing processes. Notable affordability practices: • Strong connectivity shown between the program's technology development and cost reduction goals. • Tools in place for process control, manufacturing, and simulation. • Good "up-front" use of modeling and simulation to define the ManTech process needs for both the military and commercial application – there is cost sharing to reduce the cost. • Specific plans for affordability metrics such as teaming, IPT training, use of IPPD tools, and a transition plan.
Next Generation Transparency (1997/1998)	Air Force ($5.7M) program to develop affordable transparency systems with 80% reduced production costs, 20% lower weight, 90% fewer parts, and reduced change-out time. The first efforts demonstrated the feasibility to design (with CAD) and manufacture transparencies, while the Phase 2 contracts, presently underway, are to adapt the technology to meet future requirements of the Joint Strike Fighter (JSF) and the F-22. Notable affordability practices: • Good customer ties (i.e., JSF, F-15, and F-22). • Contractual requirements to practice affordability using the AF S&T IPPD Process Model. • Leveraged funds from various sources such as Wright labs (AFMC), industry and the Navy. • Programmed funds into the contract for extensive training in IPPD, six sigma, CAIV and design of experiments. • JSF Transition Plan required as part of this program plan. • Exit criteria and quantitative goals defined and tracked.

AIR PLATFORMS DEFENSE TECHNOLOGY AREA (CONT'D.)	
Unmanned Combat Air Vehicle (1999)	Joint DARPA/Air Force, Advanced Technology Demonstration with funding of $110Mover 3 ½ years. Objective to design, fabricate and flight test a revolutionary tactical airpower system that augments the manned force, enables preemptive and reactive suppression of enemy air defense and provides persistent all-weather capability for high-risk and high-payoff missions. Goal is to provide this capability at an O&S cost that is less than 25% of current aircraft O&S costs and at an acquisition cost that is less than one-third of new manned aircraft. Notable affordability practices: • Competing contractor teams have implemented IPPD principles during first phase. All team members have attended IPPD training. Multidisciplinary IPTs are aligned with work breakdown structure. • Affordability figures of merit are key elements of the program. All technologies must "buy their way onto the program." • System maturation plan in preparation for low risk transition into EMD. • The government management team includes all of the key stakeholders – warfighters, acquisition, S&T. • After completion of competitive Phase I, both government and industry will be represented on all key IPTs. • Contract incentive plan established to encourage affordability best practices.
Joint Expendable Turbine Engine Concept (1999)	Four-year, $9.8M joint Air Force, Navy and DARPA program in which the objective is to provide a propulsion technology base of proven, high-payoff, components aimed at both new and engine upgrades/derivatives for subsonic/supersonic missiles/unmanned air vehicles (UAVs) for both tactical and strategic missions. Notable affordability practices: • IPPD supported and encouraged by management. The management IPT includes all stakeholders (government, industry, S&T and acquisition). • Contractor is using Six-Sigma tools in its decision analysis. • Program is leveraging activities including other 6.2 and 6.3 S&T, IR&D, Dual Use S&T. Cost sharing by Air Force, Navy, DARPA, and the contractor. • Contractor and government personnel are receiving affordability training and funding has been identified to support training.
MATERIALS/ PROCESSES DEFENSE TECHNOLOGY AREA	
Composite Armored Vehicle (CAV) (1997)	The CAV ATD was a key element of the Army's effort to develop lighter, more deployable & survivable ground combat vehicles. It demonstrated the technical feasibility and operational potential of composite materials for vehicle hull structure and armor. The demonstrator was designed to support the development of future lighter weight vehicles with at least a 33 percent reduction in hull structure and armor weight and with reduced development time, costs and risks. One of the two model programs originally selected by the ATF for "best practices", additional affordability details are found at Section 3.1.

MATERIALS/ PROCESSES DEFENSE TECHNOLOGY AREA (CONT'D.)	
Nanoscale Coatings (1998/1999)	Navy program to reduce ship maintenance costs (over $4B in 1996) by coating parts with a protective spray (i.e., tungsten carbide cobalt – WC/Co) that increases part life, extends the period between scheduled maintenance, and allows for repair of parts vice costly replacement. Notable affordability practices: • IPT participants from the program's technology developers (e.g., industry and university developers), shipyard personnel, and the user of the nanostructured materials technology (i.e., NAVSEA CVN77). • Reduction in life cycle costs by applying these revolutionary coatings to parts. For example, applying this technology to the launch catapult yields an estimated cost reduction of about $30 million over 10 years. • State-of-the-art coatings have revolutionized the coatings industry to the point where ships that have been docked can now come back into service by repairing them with nanostructured materials technology.
Laser Eye Protection (1998)	Air Force program to develop next generation eye protection (i.e., holographic filters or eye-centered rugate filter technology) to counter an evolving laser threat. Flexible manufacturing techniques are being investigated to replace expensive visors originally developed using laser absorbing dies and reflective filters. Notable affordability practices: • Good management support – AF execs supports IPPD training; 3-day training session on IPPD conducted shortly after the April '97 Kickoff meeting. • IPT has a wide range of participants including industry, government, customers and "house of quality (HOQ)" advisors. • A Technology Transition Plan in place that contractually requires industry assessments, manufacturability analyses, and cost analyses throughout program. • Program designed to meet the joint warfighting needs of both the Air Force ACC and Special Forces (SOCOM), with a goal to include transition funding in POM 00.
Composites Affordability Initiative (1998)	Joint Air Force/Navy/Industry long range (8-10 years) initiative to develop the tools and technologies necessary to enable aircraft designers to design an "all-composite" airframe to enable reductions in cost and weight. Notable affordability considerations: • User requirements identified early on. • Multiple applications (i.e., aerospace control, air-to-surface, and special operations forces) modeled. • JSF is a committed customer. Also Rotary Wing Structures ATD, another Affordability Program, is to collaborate with AF on CAI. • IPT consists of government and the four main airframe companies (Boeing, Lockheed Martin, Northrop Grumman, and Scaled Composites), who share data and funding. • IPPD process well defined and an Executive Council consisting of industry and government members heads up the entire IPPD. • A 6 ft. graphite epoxy composite structure was initially demonstrated for the target of $150/pound versus $1500/pound manufacturing cost.

MATERIALS AND PROCESSES DEFENSE TECHNOLOGY AREA (CONT'D.)	
Modular Hybrid Piers (1999)	Four year $3.2M Navy program to develop composite reinforced concrete pier concepts in order to obtain stronger, flexible piers that require less maintenance (i.e., 80% reduction in waterfront maintenance/repair). Existing steel structures built in the 1940's need to be replaced, and this program is to determine the feasibility of replacing these old piers with composite piers that are slightly more expensive (1.0/1.05 difference in cost) but that reap the benefits of extended life. Specific technical areas addressed include a technique to bond polymer matrix composite strands to concrete piers vice rebar. Notable affordability practices: • Unit cost of building piers with composites as opposed to steel is slightly higher, however, there are potential life cycle cost savings using composite materials, the piers are modular (i.e., able to be relocated), and allow operational flexibility. • Naval Station San Diego has endorsed and is to provide 6.4 funds to the program to rebuild Pier 14 of the San Diego facility.
GROUND & SEA VEHICLES DEFENSE TECHNOLOGY AREA	
Advanced Enclosed Mast (1997)	$23M, 3-year ATD program (See Section 3.3 on case study report) that seeks to introduce composite structures into Navy surface combatants. Objective is to demonstrate an integrated composite antenna mast for surface ship applications having reduced signature, reduced topside weight, and improved antenna/sensor performance. Notable affordability practices are discussed in Section 3.3.
Future Scout & Cavalry System (1998)	Focused on meeting the Army's tactical reconnaissance armored combat equipment requirement (TRACER). As a Fast Track program, results from the 6.3 ATD will feed directly into EMD. The program is a joint U.S./U.K. effort. Notable affordability practices: • The user (at Fort Knox) has budgeted EMD funds to transition this program. • Exit criteria have been identified -- such as the minimal acceptable signature reduction detection time of 3% for the thermal optical radar. Thresholds are defined for the current baseline and at the end of the ATD. • IPPD will be contractually required when the program begins in August 1998. Texas Instruments, who helped the Army develop their IPPD methodology, will be on the team. • Good use of CAIV, especially with a high percentage of "tradable" requirements.

GROUND AND SEA VEHICLES DEFENSE TECHNOLOGY AREA (CONT'D.)	
SC-21 Manning Technology for Affordability (1998/1999)	Program to develop multi-modal watchstations that optimize human-computer interaction. Goal to change the traditional Navy approach to shipboard manning by enabling at least a 2-to-1 combat systems manning reduction with sustained performance. Notable affordability practices: • IPT structure utilizes multidisciplinary team from 6.1, 6.2, 6.3, 6.4 communities and the Fleet operators. • Excellent communication system in use with quarterly IPT Reviews, frequent communications via a website, monthly electronic reporting, and biweekly video teleconferences. • Unit/life cycle savings – multi-modal watchstation function combined to reduce the number of functions for cost avoidance of \$1.1M/year/ship & overall life cycle cost savings estimated at \$100K/watchstation. • Multiple platforms being analyzed for multi-modal watchstation technology application, include SC21, CVX, AEGIS Block 6 and 7, LHX, and NSSN.
Reduced Ships Crew by Virtual Presence (RSVP) (1999)	Navy ATD (\$14.5M) is to demonstrate a multi-functional, fault tolerant, microelectromechanical system (MEMS) based, wireless sensor network for real-time internal ship situational awareness. Purpose is to significantly contribute to DD21 manning reduction requirements by replacing the human sense, fuse and information assessment functions for monitoring and evaluating the health of machinery, structure, environment and personnel. Notable affordability practices: • IPPD approach established with an IPT structure that includes all the stakeholders including the warfighters, the primary transition customer (DD21), other potential transition customers, prime contractors and subcontractors. • IPT training planned, including refresher training on an annual basis. • Affordability metrics established and part of the program trade analyses. • Technology transition enabled by a memorandum of agreement (MOA) executed between ONR and the PEO/PM DD21. • Leveraging of existing DARPA-developed technology and is use of open systems architecture approach (application of common components across multiple systems).
WEAPONS DEFENSE TECHNOLOGY AREA	
Concentric Canister Launcher (1997)	ONR-sponsored program to develop a universal launcher for the next generation combatant ships. Notable affordability practices: • 50% LCC savings (compared to MK-41). • 30% production cost savings. • Technology development has been advocated by Chief Maintenance Office of Atlantic Fleet and has potential to apply to multiple systems (SC21 and CVX).

WEAPONS DEFENSE TECHNOLOGY AREA (CONT'D.)	
Enhanced Fiber Optic Guided Missile (EFOGM) ATD (1997)	Validate Army missile technology for precision strike at 15 km by guiding missile as it travels through the atmosphere with an online view. Notable affordability practices: • Contractual IPPD requirement. • Cost plus incentive fee contract with 50/50 share line. • Development of cost avoidance plan to help transition technology. • Extensive use of electronic drawings and simulation exercises with soldiers; maximum COTS. • Co-location of IPTs in contractor facilities. • Committed customer (Ft. Benning infantry school/XVIII Airborne Corps) to buy 300 missiles.
Objective Individual Combat Weapon ATD (1998)	Army program to apply an open systems approach to replace weapons (i.e., the M16 rifle family, M203, and modular weapon system) with one OICW that integrates many different weapons components (e.g., CCD magnifying video camera, laser rangefinder, kinetic energy module, thermal sight, etc.). The OICW is a dual munition weapon that performs high explosive, air-bursting munition as well as NATO kinetic energy projectile (5.56 mm). Notable affordability practices: • Users of the weapon are involved in the program planning from the start. • IPPD team training (QFD, design for manufacturability, Cp-Cpk, and team building) was conducted for government and industry team members for 1 week at Motorola University. • OICW provides more than 5 times the firepower and greater than 5 times the lethality at a lower cost and weight comparable to other systems. • In comparing the OICW system to ammo procurement costs, there are potentially millions in dollars of cost savings.
Large Aircraft Infrared Countermeasure (1997/1998)	Air Force program (6.3-funded at $20M over 5 years) to develop and test advanced laser IRCM technology. Notable affordability practices: • AF model for affordability in S&T contractually required to be used with good support from senior management and well-constructed IPT (with warfighter participation). • CAIV goals being implemented and tracked. • Meets joint warfighting needs of AMC, and is being reviewed by JROC. • Technology Transition Plan (TTP) in place with funds identified in EMD to effect transition.

WEAPONS DEFENSE TECHNOLOGY AREA (CONT'D.)	
Integrated Situation Awareness and Targeting ATD (1999)	Army program to integrate radar, missile and laser warning spectrums to provide full dimensional threat protection and to increase the number of sensors in the tactical battlefield to provide real-time target location, identification and hand-off. Extensive test and evaluation will be conducted as part of the ATD. Notable affordability practices: • Acquisition program managers endorse transition of technology and funding is planned for EMD. • Exit criteria established by warfighter, acquisition and S&T communities. • Software and hardware affordability metrics specified and include design to unit production cost. • Open system architecture approach being applied to technology insertion. • IPT structure established including all stakeholders in government and industry. • IPPD training of both government and industry team members. Additional training is planned during the first year of the program. • Leveraging of completed and on-going S&T and product improvement activities. • Clear management support for affordability.
Objective Crew Served Weapon (OCSW) (1999)	This model program of affordability practices is a new, four-year, $30M Army 6.2/6.3 funded program that includes $2M from the Marine Corps. The objective is to develop and demonstrate a lightweight, 2-man portable weapon with overwhelming lethality for the dismounted soldier that includes lightly armored vehicle penetration capability. The approach includes the development and demonstration of successive levels of sub-system integration and capability. Notable affordability practices: • IPPD tools and procedures are understood and are being applied. • IPPD is required in contracts. • QFD implemented with the customer to identify key issues. • Life-cycle IPTs in-place with specific operating procedures, guidelines, and empowerment. • User involvement maximized to ensure first time product solution that complies with operational requirements. Large emphasis on design for manufacturability, reliability and maintainability. SOW requires "design for production affordability". • Leveraging of Army ManTech activities and of commercial processes. Also use of common components across multiple platforms. • Transition to the PM Small Arms is planned and EMD funding is planned. • MOA in preparation. • Specific exit criteria have been defined including affordability goals. ATD metrics being used to assess progress toward ATD goals, EMD entry risk and Operational Requirements Document (ORD) compliance. • ATD co-located with the acquisition program manager.

SENSORS/ELECTRONICS DEFENSE TECHNOLOGY AREA	
Power Electronic Building Blocks (1997)	The Navy PEBB program is to enhance the affordability of a military system by developing a single package with a multi-function controller that: replaces complex power electronic circuits with a single device; reduces development and design costs for complex power circuits; and simplifies development and design of large electric power systems.
Improved Space Computer Program (1997/1999)	6.3-funded Air Force space development electronics program ($55M/5 years from FY97-01) to identify, develop and demonstrate an open, affordable architecture that can meet the requirements for the majority of next generation DoD space systems. Phase 2 and 3 are to investigate flexible, scaleable open architecture systems for next-generation DoD space systems. Notable affordability practices: • SOW requires that affordability assessment be made for all proposed Phase 1 ISCP architecture concepts. • Good examples of affordability measures provided such as developer surveys, HOQ, sensitivity analyses, etc. HOQ indicates that acquisition and warfighter community committed to implementing the results of this program. • Leveraging of work on NASA Jet Propulsion Lab Remote Exploration and Experimentation Project.
Ballistic Wind Sensors (1997)	Air Force program to develop affordable multi-platform eye-safe airborne wind profiler system. Notable affordability practices: • Dual use applications for technology. • Strong IPPD/IPT structure. • Leverages ManTech funds. • Good use of producibility tools, including assessment of contractor's manufacturing capabilities, investments in CAD tools, use of a bottoms-up cost model, and lab experiments to validate tolerance for key components.
3-D Optical Memory (1997)	$5M, 3-year, 6.3-funded Air Force program being conducted by Call Recall, a group of university professors, to develop optical device technology to store digital data in 3D. Potential dual-use program that could lead to better computer storage devices for commercial use.
Integrated Sight Module (1997)	$6M Army program with Texas Instruments (awarded in June 1996) to design and build 12 integrated sight modules to deliver to the Land Warrior program for evaluation. Program purpose is to develop technology for target location and "call-for-fire". The 21st Land Warrior and the Thermal Weapon Sight programs are both customers for this technology and are actively involved in the program developments. Notable affordability practices are: • Contract IPPD requirements include tailored strategy for IPPD, establishment of process/quality goals via estimation of sigma levels (currently at 4.4 sigma), affordability status reporting at program reviews, and well-defined exit criteria (i.e., weight, performance and power). • Users interviewed by contractor in order to develop program goals. • Program focus on technology integration of completed design; plans for EMD and technology transition being developed. • Team and IPPD training was conducted by contractor before contract was let and funds for training have been set aside.

SENSORS/ELECTRONICS DEFENSE TECHNOLOGY AREA (CONT'D.)	
Miniature Module Microwave Receiver (1998)	Navy program to develop series of 5 common MMIC RF modules. These high performance miniature RF receivers and RF channelizers are to be integrated across a variety of platforms such as aircraft, submarines, and ships. Notable affordability practices: • Reduces size, weight and cost of RF receiver – 1 "black box" replaces 4 components. • R-300A MIMIC receiver replaces the TN-613 tuner for a weight savings of over 30 lbs., volume reduction from 900 cu. in. to 11.5 cu. in and a cost from $120K each to less than $50K each. • Weight savings translates into fuel savings. • Customer committed -- Navy Cooperative Engagement Capability is targeted for this technology in 2000. • MTBF expected to increase to greater than 1,000 hours (previously less than 100 hours) for added life cycle cost savings. • Applicability of new receiver to a wide range of platforms.
Acoustic Sensors & Sources (1997/1998)	Navy program to demonstrate a new all-optical acoustic sensing technology that greatly reduces the cost and complexity of towed arrays. Submarine towed arrays are to replace the TB-29 by the year 2000, and the Anti-Submarine Warfare (ASW) program is another prospective application. Notable affordability practices: • Focus on building smaller, lighter and more capable products. • Good connection to the customer in creating transition plans. • Cost savings ($1K versus approximately $10K cost for the TB-29 acoustic channel). • Trade studies being done to identify cost drivers, measure performance, estimate LCC, and demonstrate cost savings and overall best value to DoD. • Reduced number, cost, and complexity of acoustic (wet end) components.
Multi-Mission Common Module Unmanned Air Vehicle Sensors (1998/1999)	Army ATD in which 2 synthetic aperture radar (SAR) prototypes are being built at a target price of $7.3M. The acquisition strategy for this program includes incentives for the contractor to better this cost goal as the government and industry share in the profit (60/40). Notable affordability practices: • The contractor performing cost/performance tradeoffs. • Two IPTs established – one team to discuss contractual issues and a second IPT, "Sensor Suite Commonality Tradeoffs", to discuss technical trades. Each team consisted of both government and industry members. • Customer (TRADOC) has specified unit production cost goal. • CAIV used as an affordability tool. • Training in IPPD, Taguchi methods and QFD. • Transition path to Tactical UAV for EMD identified and production funding in POM.

SENSORS/ELECTRONICS DEFENSE TECHNOLOGY AREA (CONT'D.)	
Multifunction Staring Sensor Suite (1999)	Army ATD to provide "leap ahead" target acquisition technology for future ground vehicles with an emphasis on the Scout. Program is addressing most affordable combination of infrared (IR) bands that will enable improved target detection, recognition and identification. Notable affordability practices: • IPPD is contractual requirement. • Affordability goals established with production cost estimates for affordability tradeoffs. The baseline concept and costs have been identified. Metrics are being monitored at all program reviews. • The transition customer (PM Scout) is on the IPT. • Application Steering Group established that includes the warfighter and potential acquisition representatives to facilitate effective transition. Close collaboration with PM Night Vision to assure technical maturation sufficient for adoption by future ground systems beyond Scout. • COTS, open architecture approach used and leveraging of prior detector/cooler ManTech work.
Advanced Common Electronic Modules (1999)	Navy program ($12.8M/4 years) to reduce the life cycle cost, weight, power and wiring of air, surface, undersea and space platforms by developing highly integrated common RF electronic modules capable of transmitting and receiving signals between 50MHz and 45MHz for radar, electronic warfare, communication and data link functions. Notable affordability practices: • Program organization structured as a high-level IPT with both government and industry participants including the prime contractor for the transition target. • Program appears to have a solid, systems engineering approach to achieving the objective and mitigating risks.
Enhanced Recognition & Sensing LADAR (ERASER) (1999)	Air Force program ($5.5M) to extend the capabilities of the FLIR/Designator Targeting Systems (FDTS) to improve non-cooperative target identification for combat missions. Laser illuminated ID techniques are being integrated into the FDTS to achieve high resolution TV-like images. Notable affordability practices: • Program decision milestones heavily influenced by affordability concerns. • IPTs formed and training in process. • There is leveraging of other S&T funding of all three Services and DARPA to reduce program risk.

SENSORS/ELECTRONICS DEFENSE TECHNOLOGY AREA (CONT'D.)	
Affordable Multi-Missile Manufacturing (1999)	DARPA ATD to demonstrate advanced missile design and manufacturing enterprise concepts and systems. Focuses on missiles, seekers, and guidance control section (typically 60% of a missile's cost). Through reduction of design in manufacturing span times, development of common architectures, and introduction of improved technologies without significant redesign, M3's goals are to reduce costs of mature missile systems by25% and developing systems by 50%. Notable affordability practices: • Emphasis on rapid product development, enterprise integration/information sharing between primes and suppliers and improved supplier management practices. • All stakeholders, including industry and PEO/PM reps, part of decision-making process. • Cost sharing between government and Lockheed Martin/Raytheon. • Formal training with the suppliers (e.g., activity-based management). • .Leveraging of internal IR&D and many S&T programs. • Use of common components across multiple platforms, including Army missile systems, BMDO technology insertion activities in the navigation area for use of common interferometric fiber optic gyro (IFOG) components across many BMDO missile systems, and a number of commercial processes. • Technology transition handled directly between the two missile contractors and program executive offices.
SPACE PLATFORMS TECHNOLOGY AREA	
Thin-Film Space Solar Cells (1999)	Air Force program whose objective is to increase power on-orbit while decreasing power system mass and cost. Specifically, this effort is developing lightweight, flexible array structures with 12-15% efficient solar cells with 150-200W/Kg costing less than $50/W. Applicability is for next generation, defense-unique small satellite missions. Notable affordability practices: • Plans to incorporate affordability tools and practices within this new effort. • IPT formed including government and industry. SPO representatives will be invited to attend meetings. • Leveraging DARPA and other Air Force 6.1 & 6.2 solar cell development programs.
High Efficiency Solar Cells (1999)	This is a new, three-year, dual use S&T Air Force program with $9M plus funding that began in FY99. This is a fifty/fifty industry/government cost share effort in which the objective is to develop a 35% efficient solar cell to increase power at a given size (W/M^2). Benefits include reduced storage volume, aerodynamic drag and radar cross-section at a specific power level, and the ability to provide sufficient power at a reasonable size for Largesats and Monstersats. Notable affordability practices: • Leveraging of Navy, NASA, BMDO, DARPA and other Air Force space technology alliance efforts to improve solar cell technology. In addition, the vendors for the commercial satellite industry are the same vendors funded under this effort. • IPT formed including government, industry and SPO representatives before program start, and training is planned. • Specific cost per watt goal has been established. • Six sigma statistical process control techniques being implemented. • Exit criteria include a specific cost goal and transition.

INFORMATION SYSTEMS TECHNOLOGY AREA	
C2 Protect (1999)	Army five year ATD ($34M) to develop, integrate and validate hardware and software tools that will secure the systems and networks of the First Digitized Division (FDD) and beyond. Some areas of interest include intrusion detection, situational awareness, whiteboarding, video teleconferencing on the battlefield, SINCGARS radio interoperability, and Tactical Internet. Notable affordability practices: • COTS technology used extensively with a goal to “fix” the vulnerabilities that are associated with inserting commercial technology into military systems. • Leveraging of funds with Dual Use S&T program and the customer (Division Integrated Systems Command, Control, Communications and Computers). • Though no formal transition plans are in place, there appears to be good dialogue with monthly IPT meetings that include participation by the warfighters and program executive offices (PEOs).
HUMAN SYSTEMS DEFENSE TECHNOLOGY AREA	
Next Generation Soldier System ATD (1997)	The Army’s GEN II ATD is the cornerstone program of the 21st Century Land Warrior (21 CLW) Integrated Technology Program (ITP). It is the primary effort to address future dismounted soldiers as a system and as a weapons platform. The purpose of the GEN II ATD is to enhance individual soldier’s survivability, lethality, mobility, and situational awareness. The GEN II ATD will accomplish these tasks by improving upon current dismounted soldier capabilities while reducing the size, weight, bulk and power requirements relative to current equipment as well as provide new capabilities previously unavailable to dismounted soldiers. The GEN II program, one of the two initial “model” programs selected by the ATF, is detailed in Section 3.2.
Advanced Embedded Training (1997)	Navy/ ONR-sponsored ATD program (funded at $11M over 3 years) to improve tactical team combat readiness through enhanced embedded training. Directly addresses the affordability issue of training costs as a major contributor to system life-cycle costs. Goal is to reduce pier-side and shore-based training and their associated cost. Notable affordability practices: • AET transition plan being formulated. • Customer (Navy PMS 400 AEGIS Program office) actively involved in technology development program. • Good use of COTS. • Metrics established by AEGIS team (i.e., decision making speed and accuracy is expected to improve by 25-40%, while life cycle costs of training are to be reduced). • No formal IPT training; however, program development being conducted by research psychologists who typically utilize tools for IPPD/IPT (team dynamics, QFD, etc).

HUMAN SYSTEMS DEFENSE TECHNOLOGY AREA (CONT'D.)	
Modular Aircraft Support System (1997)	Air Force 6.3-funded ($7.5M/5 year) program to improve the mobility footprint of aerospace ground equipment. Notable affordability practices: • Extensive "up-front" work in defining maximum customer (JSF) requirements (i.e., the F-16 only needs 20 kW power, not 60 kW formerly specified) • Good IPPD/IPT tool planning (use of QFD, design of experiments and six sigma). • Addressing potential savings to be gained by dual use. • Participation by Army and Navy in IPTs. • SOW requires IPPD/IPT participation by contractor. • High degree of common interfaces between future ground equipment (e.g., frames, engines, and power functions, etc.). • Good management support with attention through Armstrong labs up to the air Technical Executive office.

APPENDIX D

TRAINING AND EDUCATIONAL COURSES

TRAINING AVAILABLE RELATED TO S&T AFFORDABILITY

The courses listed below represent a sampling of what is available from industry to support the implementation of Integrated Product and Process Development principles and related methods and tools. The list is not complete, and only those courses indicated have actually been attended by government personnel from whom feedback on course quality and content has been obtained.

E.1 IPPD Overview.

Course Title	Provider	Description	Time	’98 Cost
Affordability in S&T: An Introduction	James Gregory Associates	Affordability overview with hands-on excercises. Address web-based training, metrics and value analysis.	2 Days	$595
IPPD in ATDs & ACTDs	National Center for Advanced Technologies	Short course, aimed at government & industry, Washington perspective	3 days	$100
Affordable Technology Through IPPD	James Gregory Associates	In-depth, hands-on course in methods and tools to achieve affordable new technologies. An end-to-end example is worked in class.	3.5 days	$895
IPTs & IPD	Boeing	Internal Course open to customers & suppliers	6 hrs	-
IPPD Background/ Overview	NTU (Video, Distance)	Video Course, 2 hrs/wk, 6 months, delivery over VTC (Broad Offering, Jul-Dec 93)	48 hrs	$900
Concurrent Engineering Short Course	UCLA	Definitions, concepts, tools and case studies	5 days	-
Fundamentals of Concurrent Engineering	Society of Mfg Engrs	Provides background to initiate development of detailed, company plan	2 days	$475
World Class Concurrent Engineering	MIT	MIT Video, CE Princpals, Enhanced QFD, Taguchi Qualification	4 tapes, 50 min ea	$975
Customer-Focus Product Devel. System	Raytheon	Overview of Hughes IPPD Process Implementation	2 hrs	No cost

E.2 IPTs/Teaming

Course Title	Provider	Description	Time	Cost
IPT Team Training (Dynamics & Methods)	WPAFB Campus	TQ concepts, collective analysis, process improvement	32 hrs	-
Team Leadership	T.I.	Team building, group decision making, conflict resolution	4 days	$715
Team Works	GPA/ QPC	Team selection, empowerment, basic tools	3 days	$825
IPTs & IPD	Boeing	IPD implementation, multi-disciplinary team structure, roles, responsibilities	6 hrs	-

Course Title	Provider	Description	Time	Cost
Implementing IPTs	Raytheon/ Hughes	IPT Team Definition, Roles, Deliverables	8 hrs	$104
Leading IPTs (Workshop)	Raytheon/ Hughes	IPT Management, IPT Process, Leadership Skills	16 hrs	$239
Implementation Specialist Workshop	Raytheon/ Hughes	Practical Application of IPPD Principles via IPTs	2.5 days	$401
Communicating in an IPPD Environment	Raytheon/ Hughes	IPT Communication Skills and Methods – Dialog	8 hrs	$97
Team Development Training	Raytheon/ Hughes	Four 4-hr Sessions in Team Development/Interaction	16 hrs	$286
Concurrent Engineering	Army,	Increases CE Team's Awareness of Techniques	16 hrs	-

E.3 IPPD Management

Course Title	Provider	Description	Time	Cost
A Quality Culture, the New role of Managers	Am. Supplier Inst.	Shared Decision making, Tool Selection, Team Agendas	2 days	$695
Seven Management & Planning Tools	GPA/QPC	Summary of Key Tools, including Pareto, Fishbone, etc.	2 days	$725
Risk Analysis Seminar	Expert Choice	Aimed at Marketing their Software Tool for Risk analysis	3 days	$875
Working Together in an IPT Environment	Raytheon/ Hughes	Hughes Model: How Managers Interact and Lead Teams	8 hrs	$104

E.4 Design to Cost

Course Title	Provider	Description	Time	Cost
Design To Cost	Raytheon (T.I.)	High Level Overview, DTC Principles, Benefits	1 day	$275
Fundamentals of Cost Analysis	Defense Acq. Univ.	In-Depth Acquisition Cost Analysis Training	15 days	-
Design to Cost (Including CBT)	Raytheon	Overview of Basic DTC Principles and Practice	8 hrs	$104

E.5 IPPD Design Principles – Design for Producibility

Course Title	Provider	Description	Time	Cost
Design for Six Sigma Manufacturability	Raytheon (T.I.)	Six Sigma, DPU, Variability, Cp, Cpk	2 days	$350
Design for Manufacturability	Motorola	Six Sigma, DPU Measurements, Cp, Cpk	2 days	$450
Taguchi Methods	American Supplier Inst.	Understand Robust Design, Taguchi Loss Function	1 day	$395
Taguchi Quality Engineering for Robust Design	American Supplier Inst Video	Video Overview of Robust Design Principles and Practice	1 hr	-
Six Sigma for Manufacturability	Boeing	IPD Process, impact of Manufacturing Defects, 6 Steps of 6 Sigma	18 hrs	-

E.6 Supportability

Course Title	Provider	Description	Time	Cost
IPD Design for supportability	Boeing	Supportability in Product Development, Concept, Assembly, & Packaging	6 hrs	-
Maintainability	Boeing	Basic Maintainability Concepts, Tasks and Techniques	3 days	-
R&M in Design in Systems Acq.	AFIT	Failure Analysis, Failure Modes, Testability, Accessability	10 days	-

E.7 Requirements Analysis

Course Title	Provider	Description	Time	Cost
QFD	ASI	QFD Overview, Tools, Requirements, Collection & Analysis	3 days	$845
QFD	Boeing	QFD Overview, Translate Customer Requirements into Organization Requirements	12 hrs	-
Enhanced QFD	MIT	QFD Integrated with the Pugh Concept et al Enhancements	5 tapes	$975

E.8 Design of Experiments

Course Title	Provider	Description	Time	Cost
Design of Experiments Overview	WPAFB	Conceptual Overview, Role & uses of DOE	8 hrs	-
Design of Experiments	Raytheon (T.I.)	In-Depth DOE, Latest Techniques, Hands-on	4 days	$700

E.9 Value Engineering

Course Title	Provider	Description	Time	Cost
Value Analysis & Value Engr.	Amer. Supplier Institute	Overview, Benefits, Relationship between VA/VE and QFD	2 days	$850

E.10 Cost Analysis

Course Title	Provider	Description	Time	Cost
Fundamentals of Cost Analysis	Defense Acq. Univ.	Enables entry-level DoD personnel to prepare weapon system LCC estimates.	15 days	-
Software Cost Estimating	Defense Acq. Univ.	Software cost estimating for practitioners. Software life cycle mgmt., architecture, interoperability, design approaches, metrics, capability evaluations, reuse.	7.5 days	-
Executive Cost and Price Analysis	Defense Acq. Univ.	Advanced pricing techniques for estimating costs in large procurement actions. Statistical accounting tools, cost estimating relationships, etc.	10 days	-
Reliability and Maintainability	Defense Acq. Univ.	Overview of R&M activities, based on policies in DoD 5000.2 (Defense Acquisition Mgmt. Policies), relationship to Logistics Mgmt. & Sys. Engineering	2.5 days	-

E.11 Other Applicable Courses Available from the Defense Acquisition University (DAU).

DAU consolidates and integrates education and training for more than 110,000 people in the Defense

Acquisition Workforce. Consortium member schools provide more than 85 acquisition courses to entry, intermediate, and senior level civilian and uniformed personnel to allow them to attain certification in one or more of the 11 defense acquisition career fields. A sampling of course offerings follows:

- AUD 4120 Statistical Sampling. Statistical Sampling concentrates on the knowledge and skill necessary to perform statistical sampling in the contract audit environment.

- BCF 101 Fundamentals of Cost Analysis. (15 days course) Fundamentals of Cost Analysis enables DoD personnel new to the cost estimating field to prepare materiel system life cycle cost estimates. Topics include a statistics review, regression analysis, learning curves, risk analysis, software cost estimating, exploratory data analysis, inflation adjustments, cost as an independent variable (CAIV), analysis of alternatives (AOA), contract cost structure, earned value, cost estimation for budget preparation, and economic analysis

- BCF 204 Intermediate Cost Analysis. The course emphasizes the development and application of cost analysis techniques and interpretation of the results.

- BCF 206 Cost Risk Analysis. Cost Risk Analysis prepares cost analysts to model the cost risk associated with a defense acquisition program. Topics covered include basic probability concepts, subjective probability assessment, goodness-of-fit testing, basic simulation concepts, and spreadsheet-based simulation. Practical exercises, a small-group workshop, and a capstone article review reinforce techniques taught.

- BCF 207 Economic Analysis. Economic Analysis prepares students to conduct economic analyses of materiel systems. Topics covered include multiple-attribute decision analysis, cost analysis, present value analysis, and sensitivity analysis. Students apply their expertise in practical exercises and a group workshop.

- LOG 203 Reliability and Maintainability. (2.5 day course) The course concentrates on R&M-related activities throughout the acquisition life-cycle. The aim is to enable logistics managers to understand the relationships between R&M (engineering disciplines) and acquisition logistics; and to more effectively evaluate the potential impact of R&M decisions on the logistics aspects of a systems acquisition program.

- PQM 101 Production and Quality Management Fundamentals. An entry level course that emphasizes basic production, manufacturing and quality assurance principles, policies, processes and practices used in DoD. It exposes participants to manufacturing and quality scheduling, and control techniques as well as production surveillance activities. Course content includes systems engineering, initiatives and trends, performance specifications, material control, source selection, quality assurance, technical support, and analytical tools.

- PQM 201 Intermediate Production and Quality Management. The Intermediate Production and Quality Management course emphasizes journeyman level production, manufacturing, and quality assurance principles, policies, processes and practices used in DoD. Students follow a curriculum which exposes students to manufacturing and quality processes, scheduling and control techniques, surveillance activities, and systems level production and quality planning.

- PQM 301 Advanced Production and Quality Management. The course investigates day-to-day decision making issues relevant to successfully managing three core technical tasks in DoD acquisition: systems and process development, manufacturing, and product quality management. It stresses the logical thinking process and the ability to identify and effectively work within policy, regulatory, technical, or physical constraints to management effectiveness.

- SYS 201 Intermediate Systems Planning, Research, Development and Engineering. This course covers steps in the system engineering process, requirements analysis, functional analysis and allocation, synthesis, and systems analysis/control. Specific techniques introduced include the systems engineering management plan, the functional flow diagram, requirements allocation sheet, work breakdown structure, design reviews and audits, design to cost influence, technical performance measurement programs, configuration management, developmental baseline, risk identification, and management. Special emphasis is placed on characteristics of a system such as life cycle cost affordability; readiness/supportability; reliability; testability and producibility.

- SYS 301 Advanced Systems Planning, Research, Development, and Engineering. This course uses a facilitated case study to help students become more effective in the use of the science, technology and systems engineering processes and procedures that must be followed during each phase of a system's life cycle. Students will employ requirements analyses, risk management, technical performance measures, trade-off analyses, configuration and data management, technical reviews, forecasting, design of experiments, work breakdown structures, and specification and statement of work tailoring to control and evaluate the evolutionary design of a target system. Special emphasis is placed on exploring the relationships between science and technology, systems engineering, and acquisition management.

CONTACT: Defense Acquisition University
Email: http://www.acq.osd.mil/dau/